STUDIES ON CERTAIN SELECTED LIVE FEED ORGANISMS USED IN AQUACULTURE WITH SPECIAL REFERENCE TO ROTIFERS (FAMILY: BRACHIONIDAE)

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VERSOVA, MUMBAI-400 061

by

ANITHA. P. S, M. F. Sc.
(Reg. No. Ph. D. 96)

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
P.B. No. 1603
KOCHI – 682 014, INDIA

AUGUST 2003

भा कृ अनु प
I C A R

केन्द्रीय समुद्री मात्स्यिकी अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद)
पोस्ट बॉक्स सं 1603, एरणाकुलम, कोचीन-682 014

Phone: (Off) : 394867/.....Ext 391407
Telegram : CADALMIN EKM
Telex : 0885-6435 MFRI IN
Fax : 91-484-394909
E-mail : mdcmfri@md2.vsnl.net.in

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
POST BOX No. 1603, ERNAKULAM, COCHIN-682 014

Dated: 25 August 2003

CERTIFICATE

Certified that the thesis entitled **"STUDIES ON CERTAIN SELECTED LIVE FEED ORGANISMS USED IN AQUACULTURE WITH SPECIAL REFERENCE TO ROTIFERS (FAMILY: BRACHIONIDAE)"** is a record of independent bonafide research work carried out by Miss. **ANITHA. P. S.** during the period of study from September, 1998 to September, 2001 under our supervision and guidance for the degree of **Doctor of Philosophy in Fish and Fisheries Science (Mariculture)** and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

Major Advisor/Chairman

Rani Mary George

(Dr. Rani Mary George)
Principal Scientist,
Fishery Environment
& Management Division

Advisory Committee

(Dr. Gopakumar, G.)
Principal Scientist
Pelagic Fisheries Division

Prabhakaran N

(Shri. K. Prabhakaran Nair)
Principal Scientist (Retd.)
Molluscan Fisheries Division

(Dr. M. Srinath)
Principal Scientist
& Head, Division of Fishery
Resources Assessment

(S. Jasmine)
Scientist (SG)
Fishery Environment
& Management

DECLARATION

I hereby declare that the thesis entitled "**STUDIES ON CERTAIN SELECTED LIVE FEED ORGANISMS USED IN AQUACULTURE WITH SPECIAL REFERENCE TO ROTIFERS (FAMILY: BRACHIONIDAE)**" is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

Anitha. P.S

(ANITHA. P. S)
Ph. D. Student
Central Institute of
Fisheries Education

27 August 2003
Kochi

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सारांश

देश में केरल के दक्षिण - पश्चिम समुद्र तटों में पाए जानेवाले मछली खाद्य जीव रोटिफरों के वर्गीकरण, पारिस्थितिकी और जैविकी इस अध्ययन का विषय है. अध्ययन में जैविक और अजैविक प्राचलों की तुलना में रोटिफरों के जाति संघटन, जीवसंख्या सधनता और वितरण की खोज की गई. भारत में ब्रकियोनिडे कुटुम्ब के रोटिफर जलकृषि में उपयुक्त किये जानेवाले सब से अनुयोज्य खाद्य जीव माने गए हैं. इसको सकेंन्द्रित करते हुए किए वर्गीकरण अध्ययन में 16 वंशों और 12 कुटुम्बों में होते हुए 44 रोटिफर जातियाँ पहचानी गईं. इन में रोटिफर ब्राकियोना की 3 जातियाँ (*बी.डाइकोटोमस रिडक्टस, बी.कोस्टि* और *बी. आरसियोलारिस निलसोनि* भारत में नई पहचानी गई है तो 2 जातियाँ *बी. क्वड्रिडेन्टाटस मिराब्लिस* और *बी. कालसिफ्लोरस बोरगेरटी)* केरल में नई है. बी.रोटान्डिफोर्मिस इसटोनियाना को गलत में पहले केरल के दलवापुरम में पाई जानेवाली *बी. प्लिकाटिलस* 'एस' के नाम में वर्गीकृत किया था. इस अध्ययन में इसको अलग करके भारतीय रोटिफर के रूप में पुर्नवर्णन किया. इसी प्रकार भारतीय रोटिफर में *बी. हावनेइनसिस ट्राहिया* का भी पुर्नप्राप्ति और पुर्नवर्णन किया. इसका पहला नाम *बी. फोरफिकुला केरलियनसिस* (इरिंजालकुडा) था. केरल में रिपोर्ट की गई कई जातियाँ सामान्य और सर्वदेशीय हैं. भारत के समुद्रों में पाई जानेवाली जातियाँ जैसे *बी. डाइकोटोमस रिडक्टस* और *बी.कोस्टी* जो पहले स्थानिक आस्ट्रेलियाइ जाति मानी गई थी, पर किए गए अध्ययनों ने इनके भारतीय प्राणिजातों से निकटतम सम्बन्ध सूचित किया. पारिस्थितिक घटक जैसे शरीर-वृत्तिक और रासायनिक स्वभाव, शैवालों का फुल्लन, रोटिफरों की प्रचुरता और जाति वैविद्यता पर अध्ययन चलाए गए. लवणता और पोषक तत्व इनके प्रचुरता का कारण देखा गया जबकि शैवालों का फुल्लन सब से महत्वपूर्ण घटक. वेलि-आकुलम में पाई गई प्रचुर जातियाँ *बी.आंगुलारिस, बी.प्लिकाटिलस,बी.कल्सिफोरस ,एफ.टर्मिनालिस* और एफ. लोंबिसेटा थी जबकि पून्तुरा में *बी.आंगुलारिस,बी. काल्सिफोरस, केरटेल्ला कोक्लियारिस* और *पोलियारत्रा वलगरिसा.* रोटिफरों की संख्या बढ़ने पर जाति वैविद्यता कम देखी गई. ब्रकियोना की छःजातियों में लवणता, तापमान, आहार प्रकार और पुनरुत्पादन प्रवृत्ति, बढती स्वरूप आदि पर अध्ययन चलाया गया. इनमें 3 रोटिफरें याने कि *बी. आंगुलारिस, बी. कॉडाटस* और बी. कालसिफोरस के जीव संख्या गतिकी पर भारत में यह पहला अध्ययन है. परिणामों ने व्यक्त किया कि अध्ययनाधीन प्रत्येक जातियों के पुनरुत्पादन शक्यता, जननक्षमता, बढती और जीवन चक्र में उपर्युक्त राशियों का स्पष्ट प्रभाव है और ये अन्योन्याश्रित भी है. *बी. आंगुलारिस, बी.कोडाटस* और बी. *कलिसिफोरस* का उच्चतम उत्पादन अनुकूल लवणता 0.5 पी पी टी देखा गया तो *बी.प्लिकाटिलस* , *बी. मुरे* और *बी.रोटान्डिफोर्मिस* के यथाक्रम 5 पी पी टी, 10 पी पी टी और 15 पी पी टी थे. पख मछली (ट्राइकोगास्टर लीन) की विभिन्न डिंभक अवस्थओं में लिए जाने वाला खाद्य जीव रोटिफरों के आकार में सह-सम्बन्ध देखा गया. टाइगर झींगा (पेनिअस मोनोडॉन) के डिंभकों को रोटिफरों से खिलाने पर उनकी अतिजीविता दर में बढती देखी गई.

ABSTRACT

The present study focuses on the taxonomy, ecology and biology of rotifers along the south-west coast of Kerala, India. Species composition, population density and distribution of rotifers in relation to various abiotic and biotic parameters were investigated at three stations in Veli – Aakulam and at two stations in Poonthura estuaries from February 2000 to January 2001. Based on a review of the history of taxonomy, a comprehensive and systematic study on brachionid family was conducted realizing its importance as potential live feed in aquaculture practices in India. Forty four species of rotifers belonging to 16 genera and 12 families are recorded. Among these, *Brachionus dichotomus reductus*, *B. kostei* and *B. urceolaris nilsoni* are new records for India and *B. quadridentatus mirabilis* and *B. calyciflorus borgerti* are new records for Kerala. The three species under the *B. plicatilis* complex are taxonomically segregated and redescribed. Similarly, *B. havanaensis trahea* is recovered and redescribed from India for the first time. Its earlier name was *B. forficula keralaiensis* from Irinjalakuda (Kerala) as a variety of *B. forficula*. Many are common and cosmopolitan. Presence of *B. dichotomus reductus* and *B. kostei* in Indian waters, considered earlier as endemic Australian species, has thrown new light on the discontinuous distribution as well as the close affinity of the fauna between India and Australia. The impact of physico - chemical parameters and algal blooms on the occurrence, abundance and species composition of rotifers in two estuaries are delineated. Salinity and nutrients significantly correlate with the estuarine abundance while algal blooms appear to be the most important factor especially in Veli-Aakulam. *B. angularis*, *B. plicatilis*, *B. calyciflorus* and *F. longiseta* are the dominants in Veli-Aakulam, whereas *B. angularis*, *B. calyciflorus*, *Keratella cochlearis* and *Polyarthra vulgaris* in Poonthura. High population density resulted in low species diversity and vice-versa in the study area. The impact of salinity, temperature, feed type and feed concentration on reproductive potential and life table parameters of six brachionid rotifers namely *Brachionus angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis*, *B. murray* and *B. rotundiformis* are studied. Of these, population dynamic studies on *B. angularis*, *B. caudatus* and *B. calyciflorus* in India are conducted for the first time. The results suggest that all the variables significantly influenced the reproductive potential, fecundity, lifespan and growth of the species individually and in turn interacted with each other in varying magnitudes. The optimum salinity for the maximum production of *B. angularis*, *B. caudatus* and *B. calyciflorus* is registered at 0.5 ppt, whereas the same for *B. plicatilis*, *B. murray* and *B. rotundiformis* is at 5 ppt, 10 ppt and 15 ppt respectively. The influence of finfish (*Trichogaster leeri*) larval age on the rotifers of different sizes illustrated a significant relationship between the larval age and size of the prey. The suitability of rotifers as live feed for the tiger shrimp (*Penaeus monodon*) larvae is evaluated and the survival is significantly higher in the diet with rotifer group than in the diet without rotifers.

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PREFACE

With an extensive coastline of 8129km, 0.5 million km^2 of continental shelf, 2.02 m km^2 of EEZ and an annual fishery potential of around 3.9mt the Indian marine fishing sector plays a significant role in the economy of the country through employment generation, foreign exchange earning and above all by providing cheap protein rich food for the people. However, the Indian fishery is confronting serious problems since the capture fishery would attain the maximum sustainable yield in the near future. Taking into consideration the growing demand for seafood in the domestic and foreign sectors, and the near - optimal exploitation of stocks in the inshore waters and the potential yield in the EEZ, greater emphasis has to be given to scientific, sustainable mariculture. Therefore, the need of the hour is to evolve suitable technologies for controlled breeding, seed production, feed formulation and farming technologies for all cultivable species of finfish and shellfish. In India, brackish or marine farming is restricted to shrimp farming, owing to the high export potential of penaeid shrimp. But the shrimp farming sector encountered problems of disease out breaks and this sector has become less profitable. Though the technology of farming and artificial seed propagation of a few fishes such as mullets (*Mugil cephalus*), milkfish (*Chanos chanos*) and pearlspot (*Etroplus suratensis*) have been developed, the successful commercial culture of these fishes is yet to be perfected. Similarly, commercial mariculture of the potential species such as groupers, lobsters and crabs along the coastal belt has not been established till date in India. The major constraint is the non-availability of indigenous technology for the hatchery production of finfish and shellfish seeds in adequate quantities. At present there is only one finfish hatchery in the country, established by the CIBA for seabass (*Lates calcarifer*) seed production, and that explains the present status of marine finfish culture in India. Though induced breeding of mullets (*Mugil cephalus* and *Liza macrolepis*) had been successfully carried out

(Abraham *et al.*, 1995, 1999), larval rearing on a commercial scale was not successful. Similarly, CMFRI has succeeded in breeding the grouper *Epinephelus tauvina* another fast growing fish with great national and international demand, but the larval rearing of this species was also not successful. Therefore, spawning and captive brood stock development and development of proper technology for the hatchery production of seed for all potential fish species is the challenging tasks facing marine and brackish water fisheries research organizations.

One major problem in mariculture is the successful larval rearing of marine fishes in the hatchery, since most of the larvae generally hatch at an early stage in their development. These small larvae (most of them in the range of 2 mm to 7 mm in total length) lack functional organs at the time of hatching and have relatively small yolk reserves. The onset of exogenous feeding is concurrent with the primitive digestive system as well as the small mouth gape critical for successful first feeding. Therefore, nutrition at this early stage is very critical, and larval survival is entirely dependent on the availability of first feeds in sufficient quantities. Once this problem is solved through suitable nutritionally enriched feeds, either live or formulated, a major breakthrough could be achieved in mariculture. Because of the advantages of easy availability, of not contaminating the water in the rearing tanks, high palatability, high acceptability and promoting high growth rates, live feeds are considered the most suitable first feeds for finfish and shellfish larvae. Therefore, the success of a finfish hatchery, especially in the early larval stage is exclusively dependent on the production of high quality live feed organisms in sufficient quantities. Thus, live feed production has become the backbone of the larviculture industry. However, at present in India one of the major bottlenecks in commercial larval rearing of marine organisms is the non-availability of large quantities of suitable live feed organisms at the right time. Hence, the live feed production and its successful

utilization have become one of the indispensable aspects in many hatchery operations.

Live feeds are small microorganisms available in nature. They are single cell proteins or multicell proteins such as algae, rotifers, cladocerans, mysids, *Artemia* and the like. Among the live feeds, microalgae are very important food for the commercial culture of bivalves, crustaceans and other zooplankters. Among zooplankters, rotifers are considered an excellent food for newly hatched fish larvae due to their small size, slow swimming speed, high caloric value, parthenogenetic reproduction and ability to be easily enriched with antibiotics and fatty acids.

Rotifers are a group of aquatic microscopic invertebrates and are commonly called 'wheel animalcules' as their disc like corona bears resemblance to a pair of revolving wheels due to the synchronized beating of their coronal cilia. The rotifers are well represented in freshwater plankton, but only a few species of them are found in brackish waters and fewer still in the sea.

Our knowledge of this group from Indian waters is rather scanty, despite the fact that during certain seasons they constitute a predominant portion of zooplankton, and in such cases they play an important role in the food cycle of the aquatic system. Further, the high reproductive potential through parthenogenesis is a remarkable biological and ecological feature by which the rotifers are distinguished from all other planktonic zooplankters. The significance of these organisms as first food for early larvae was first indicated by Fujita (1979) from Japan when the *plicatilis* group was used as a primary food for the red seabream larvae (*Pagrus major*) and since then the importance of their study as live food organisms has become an attractive subject in intensive research by fishery biologists.

A considerable body of information has been accumulated chiefly on taxonomy and distribution of rotifers from different parts of India. While reviewing their taxonomy, it was observed that our present knowledge of the rotifer fauna of India is still inadequate. Till now, eurotatorian fauna of West Bengal is adequately explored and that of Orissa, Punjab, Andhra Pradesh, Kerala and Jammu and Kashmir is moderately known. Except for a preliminary account of the rotifers of Bihar by Sharma *et al.* (1992), there is practically no detailed systematic account including the species group, species and subspecies/forms of the rotifer fauna from any of the Indian states. Among the different rotifers, the species belonging to the genus *Brachionus,* especially *B. plicatilis* and *B. calyciflorus,* were used as first live food for various marine and freshwater fish larvae. However, the brachionids exhibited polymorphism related to extrinsic factors (cyclomorphosis). Because of this polymorphism the taxonomy of this genus is very confusing to biologists. For example, in earlier literature in the *plicatilis* group rotifers were named the so-called 'L' (Large) and 'S' (small) types depending on the size of lorica. In spite of this it has not yet been studied then whether these two types are different at the species level or simply they are two extremes of the form (ecomorph) under a single species. Later on, Segers (1995) reviewed the taxonomic status of these rotifers based on the morphological and genetic studies of Fu *et al.* (1991, 1993) and reclassified this group into two separate species. Now these rotifers are termed *B. plicatilis* (former 'L' type) and *B. rotundiformis* (including both 'ss' and 'SM' or 'S' by aquaculturists). However, in India no attempt has been made to review the taxonomic status of this group and other rotifers, eventhough these rotifers have been reported from the estuaries and backwaters of Kerala by Gopakumar (1998). Hence a study of the planktonic rotifers of southern Kerala was initiated in February 2000.

While reviewing the studies on rotifers, it was noted that the brachionids, especially *B. plicatilis,* are important live feed for crustaceans and fishes very common in estuaries and freshwaters of Kerala. However, other than *B. plicatilis*

and *B. patulus* there is practically no information on the biology of other brachionids.. Hence it was felt that detailed studies on the population characteristics and reproductive biology of six common rotifers namely *Brachionus plicatilis*, *B. murray*, *B. rotundiformis*, *B. angularis*, *B. caudatus* and *B. calyciflorus* will be useful in mass production and evaluation of the suitability of these rotifers as a first live food for finfish larvae. Keeping this in view, a study on the taxonomy, ecology and biology of brachionid rotifers of the southern Kerala was undertaken, and the results are embodied in the present thesis entitled "Studies on certain selected live feed organisms used in aquaculture with special reference to rotifers (Family: Brachionidae)".

The thesis is presented in six chapters.

Chapter I deal with taxonomy of species belonging to the family Brachionidae. It includes a brief description of 22 species including four subspecies and forty forms along with illustrations of their salient features referred to in the text.

Chapter II deals with the hydrography, species diversity and population characteristics of planktonic rotifers from two estuaries. It describes the influence of physico - chemical parameters on their population density and distribution.

Chapter III and IV describe the effects of selected physico - chemical parameters and feed on the reproductive potential and life table parameters of six rotifers *B. angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis*, *B. murray* and *B. rotundiformis*.

Chapter V deals with the impact of rotifers of different sizes on the survival and growth of early finfish larvae.

Chapter VI is exclusively on the survival and growth of larval shrimp fed on rotifers.

CHAPTER I

SYSTEMATIC ACCOUNT OF ROTIFERS WITH SPECIAL EMPHASIS ON FAMILY BRACHIONIDAE

INTRODUCTION

Systematics is a dynamic science since the taxonomy of the flora and fauna are in a constant state of flux. No group of animals or plants can ever be said to have achieved their final status in taxonomy because new species are constantly being discovered in different parts of the world. Their discovery may ultimately lead to the diversification of an old genus into many new ones or the creation of a new genus to include the new species. The validity of a nominal species may also become questionable after a period of time. Hence, periodic revisions on the taxon are necessary so as to incorporate new discriminatory details and allocate new species to their proper taxonomic positions.

There may be a diversity of opinions regarding who was the first to publish a paper on rotifers and who first established a scheme of rotifer systematics based on a practical description of morphological details in a wide range of species including those new to science. The arrival of the microscope in the seventeenth century by Leeuwenhoek made possible the discovery of rotifers and since then, these organisms have drawn world wide attention of amateur naturalists as well as professional hydrobiologists because of their intricate structure, profusion of body forms, wider distribution and easy availability. But in India, studies on this group date back to the later part of the nineteenth century. An excellent review of literature on rotifers had been provided by Sharma (1991). Nevertheless, a brief survey of the systematic studies on rotifers is provided below.

In the beginning, all microscopic animals were called as 'Infusoria' and not distinguished from Protozoa. Therefore, the earlier workers such as Linnaeus (1758), Pallas (1766) and Müller (1773, 1786) have placed rotifers under the phylum' Vermes'. However, the term "Rotifères" was first coined by Cuvier (1798) and afterwards Du Trochet (1812) was the first to recognize the

'Rotifers' as a group of animals higher in structure than zoophytes (coelenterates) and he gave the correct explanation of this Latin word, 'Rotifères' (= rotating wheels) because in rotifers, the coronal disc with synchronous beating of its cilia looks like 'rotating wheels' due to an optical illusion. Hence rotifers were commonly called 'wheel animalcules'. Although Ehrenberg (1838) was the first to separate rotifers from Protozoa, under the name 'Rotatoria', the name proposed by Du Trochet (1812) has been widely accepted. Thus, Ehrenberg (1838) has proposed the primitive form of rotifer classification in his book '*Die Infusionsthierchen als vollkommene Organismen*'. But his classification was criticized by later workers due to the unfounded division between different groups within the rotifers. Later, Dunjardin (1841) grouped the rotifers into three groups depending on the mode of locomotion namely sessile forms, swimming forms and swimming and creeping forms. This formed the foundation of the classification of Hudson and Gosse (1886-1889); they were the first to establish a scheme of rotifer systematics based on a practical description of morphological details in their book '*Rotifera or Wheel Animalcules*'. According to this classification, class Rotifera had four orders namely Rhizota (for sessile rotifers), Bdelloidea (swimming and creeping forms), Ploima (swimming forms) and Scirtopoda (swimming and skipping forms). However, they had not made any provision for the genus *Seison*. In 1899, Wesenberg-Lund (as quoted from Hyman, 1951) created the order Seisonacea for *Seison* (marine rotifer) and united this order with Bdelloidea to form the subclass Digononta with two gonads and other rotifers with one gonad were placed under the subclass Monogononta with three orders: Notommatida, Brachionida and Melicertida.

De Beauchamp (1909) was the first to study and describe the primitive form of corona. With the study on the corona, a great improvement on the rotifer's classification had been achieved by Harring (1913) who proposed the first standard classification of rotifers. He suggested five orders: Ploima, Flosculariacea, Collothecacea, Bdelloidea and Seisonacea, but the detailed classification made by Remane (1929 - 1933) laid the foundation for the

modern systematic works on rotifers. According to Remane's classification, class Rotifera had three orders: I). Seisonacea with a single family Seisonidae, one genus *Seison*; II): Bdelloidea with four families: a). Habrotrochidae, b). Philodinidae, c). Adinetidae and d). Philodinavidae; III): Monogononta. The order Monogononta was subdivided into three suborders: (A): Ploima with three super families namely Notommatoidea, Brachionoidea and Asplanchnoidea; (B): Flosculariacea with three families namely Flosculariidae, Testudinellidae, Conochilidae, and (C): Collothecacea with one family Collothecidae. The super families, in turn, included eleven families: 1: Notommatoidea with: (i) Notommatidae, (ii) Trichocercidae, (iii) Lindiidae, (iv) Dicarnophoridae, (v) Gastropodidae, (vi) Synchaetidae, and (vii) Microcodonidae; 2: Brachionoidea with: (viii) Epiphanidae, (ix) Brachionidae, and (x) Lecanidae; 3: Asplanchnoidea with the family (xi) Asplanchnidae.

Afterwards, Hyman (1951) modified Remane's classification and grouped the class Rotifera under the phylum 'Aschelminthes'. Then a significant modification has been made by Pennak (1953) and his classification was primarily based on the fundamental structure and modification of the mastax. He treated the class Rotifera as a separate phylum 'Rotatoria'. Pennak was the first to propose the families, Trochosphaeridae with genus *Trochosphaera* and Filiniidae with three genera namely *Filinia, Pedalia* (= *Hexarthra*) and *Tetramastix* under the order Flosculariacea; family Ploesomatidae with the genus *Ploesoma* and the subfamily Pseudoploesomatinae with the genus *Pseudoploesoma* under the order Ploima. Subsequently, Edmondson (1959) made modification on rotifer classification and also treated class Rotifera as a separate phylum 'Rotifera' and introduced two new families namely Tylotrochaedae with the genus *Tylotrocha* under the order Ploima and Hexarthridae with the genus *Hexarthra* under the order Flosculariacea. However, he has rejected the subfamily Pseudoploesomatinae and family Ploesomatidae, which was suggested by Pennak. Edmondson's classification is still followed by a number of workers, but he has not attempted to make any modification on the family Brachionidae

having the highest number of genera. In the same year Bartos (1959) reviewed the family Brachionidae and reduced the genera into *Brachionus*, *Platyias*, *Keratella*, *Kellicottia*, *Anuraeopsis* and *Notholca* under this family and created new families such as Euchlanidae with the genera *Euchlanis*, *Tripleuchlanis*, *Dipleuchlanis*, *Lophocharis* and *Manfredium*; Mytilinidae with the genus *Mytilina*; Trichotridae with the genera *Trichotria*, *Wolga* and *Macrochaetus*; Colurellidae (Lepadellidae) with the genera *Lepadella* and *Colurella*.

Subsequent systematic changes were made by Sudzuki (1964), De Beauchamp (1965), Kutikova (1970), Ruttner- Kolisko (1974), Pontin (1978), Koste (1978) and Nogrady *et al.* (1993). Sudzuki (1964) proposed an alternative classification based on male morphology and erected numerous additional genus and family level taxa and created a new class (Pararotatoria) for the order Seisonacea. However, his classification was not accepted by any subsequent authors. De Beauchamp (1965) united Collothecacea and Flosculariacea (as suborders; renamed Pseudotrocha and Monimotrocha, respectively) into one order namely Gmesiotrocha. Koste (1978) has presented a monograph for rotifers widely accepted as a classical textbook, 'ROTATORIA' for identification and classification of rotifers.

Studies of Snell (1989), Koste and Shiel (1991), Wallace and Snell (1993), Shiel and Koste (1993), Segers (1995) and Shiel (1995) made substantial additions to the systematics of rotifers. The monogonont families had been reviewed by Segers, 1995 (family: Lecanidae); Nogrady *et al.*, 1995 (family: Notommatidae and Scaridiidae); de Smet, 1996 (family: Proalidae) and de Smet, 1997 (family: Dicranophoridae) for the SPB publications entitled '*Guides to the Microinvertebrates of the Continental Waters of the World*' which revealed that there had been a 70% increase in the number of species from those described in the monograph by Koste (1978). Sudzuki (1999) had also presented a monograph entitled '*An Approach to the Identification of the Common Rotifers*' wherein he gave the introductory notes on the identification

of rotifers, taxonomic criteria and key to species group, species, subspecies and forms. Recently Segers (2002) has presented annotated checklist of valid family and genus group names. According to him the total number of valid rotifer species recognized to date is 1817. The largest taxon is Monogononta (1441 species) followed by Bdelloidea (374 species) and Seisonacea (2 species).

Taxonomic investigations on Indian rotifers were initiated by Anderson (1889) who studied forty-seven rotifers collected from Calcutta. Later, Murray (1906) reported thirty-two species of rotifers from Sikkim-Himalaya. Edmondson and Hutchinson (1934) studied rotifers of Yale-north Indian expedition and recorded hundred rotifers from different localities of Kashmir, Ladak, Punjab and Nilgiris (South India). These preliminary works initiated intensive faunistic studies of rotifers from the different parts of India.

The first report on rotifers from Jammu and Kashmir was given by Edmondson and Hutchinson (1934) in Yale-north Indian expedition with new records of the genus *Notholca*. Das and Akhtar (1976), Qadri and Yousulf (1982) and Jyoti and Sehgal (1980) studied the rotifer fauna in this state and added substantially to the knowledge on the rotifers of this area.

Vasisht and Gupta (1967) studied rotifers of Chandigarh, Punjab. Vasisht and Dawar (1968) gave the first description of the male of *Cupelopagis vorax* from that area. Afterwards, Vasisht and Bathish (1969, 1970, 1971) studied rotifer fauna of Punjab and supplemented more species to the faunal list of this area. Sharma (1980c) reported twenty species belonging to the family Brachionidae from Punjab while his later work together with Sharma (1984) added thirty-five species to the fauna of this state. Bathish (1992) presented a monograph on rotifers of Punjab and this resulted in important contribution to the rotifer fauna of Punjab State.

Sarma (1988) has presented a faunistic account of twenty-seven rotifers from Delhi. Nayar (1968) studied rotifers of Rajasthan and documented thirty-six rotifers including one new species, *Monostyla paradecipiensis*. Wulfert (1966) made faunistic studies in Gujarat area and had recorded eighty-seven rotifers from Baroda.

Donner (1949) described *Horaëlla brehmi* from Bihar and that was the first systematic account of rotifers from this State. More rotifers were reported from here by Nasar (1973), Laal and Nasar (1977), Singh and Shakuntala Pandey (1984, 1993), Sharma *et al.* (1992) and Shakuntala Pandey and Singh (1993).

Saksena and Sharma (1981, 1982) gave a systematic account of rotifers in Gwalior, Madhya Pradesh. Sharma and Saksena (1981), Saksena and Kulkarni (1986a), Saksena *et al.* (1986) and Saksena (1989) studied the rotifers of this area and added more species to the faunal list. Kaushik and Saksena (1991) studied the rotifer fauna of Gwalior and they documented thirteen species belonging to ten genera. They reported the presence of *Kellicottia longispina* and that was the first report of this species from India.

Arora (1962, 1963, 1965, 1966) gave a detailed faunistic account of rotifers from Nagpur, Maharashtra. Dvorakov (1963) studied the rotifers from this area and added more species to the faunistic list of this state.

Hauer (1936, 1937) had studied the rotifer fauna of Tamil Naidu. Ahlstrom (1943) reported a new variety of *Keratella quadrata* from Ootacamund Lake while revising the genus *Keratella*. Donner (1953) who examined the Brehm's material from Madras described *Trichocera ruttneri*. Brehm (1951) was the first to report and describe *B. donneri* from Madras, which is endemic to India. Pasha (1961), Michael (1966, 1973), Wyeliffe and Michael (1968) and Rajendran (1971) studied freshwater rotifers from different parts of Tamil Naidu and documented more rotifers from this area. On the

other hand Govindasamy (1988) and Govindasamy and Kannan (1991) studied the rotifers from brackish and marine environments. The monograph on rotifers of Porto Novo by Kannan and Govindasamy (1991) is a practical manual for researchers.

The rotifers of Andhra Pradesh were studied by Naidu (1967) and he reported twelve species in this area. Dhanapathi (1973, 1974, 1975, 1976, 1977, 1978), Chandra Mohan and Rao (1976) and Rao and Chandra Mohan (1976, 1977, 1984) had conducted studies on the rotifers of this State. They recorded more species from this area. Dhanapathi (1978) recorded a new variety of *Platyias* (*P. quadricornis andhranesis*), new rotifer (*B. durgae*) and created a new genus "*Pseudoeuchlanis*" having the combined characters of *Euchlania*, *Dipleuchlania* and *Squatinella* from Andhra Pradesh.

Sharma (1977, 1980a, 1987b) studied the rotifers of Orissa and recorded sixty-nine species from this State.

The systematic studies on rotifers of West Bengal was undertaken by Anderson (1889) followed by Sewell (1935) who presented a classical account of fauna thriving in a tank in the Indian Museum compound, Calcutta. Brehm (1950) recorded three species of rotifers, including *Keratella cochlearis* from this State. Tiwari and Sharma (1977) and Sharma (1978a, b, 1979a, b, c) studied rotifers of West Bengal and added more species to the fauna of this area. Sharma (1992) gave a comprehensive account of systematics, distribution and ecology of freshwater rotifers of West Bengal.

Sharma (1976, 1980b, 1987a), Patil (1978, 1988) and Sharma and Sharma (1987, 1997) studied rotifers of Assam, Manipur and Meghalaya (North-Eastern India) and recorded sixty-three species from this area.

Nayar (1965b) gave taxonomic notes on Indian species of the genus *Keratella*. Sharma and Michael (1980) had presented a synopsis of the

taxonomic studies on the rotifers from the different parts of India. In the mean time, Sharma (1983, 1987c) reviewed the status of Indian species of the genus *Brachionus* (Family: Brachionidae). Other recent observations on rotifers in India were those of Segers *et al.* (1994) and Segers and Babu (1999).

Nayar and Nair (1969) pioneered the taxonomic study of rotifers of Kerala by reporting fifteen species belonging to the family Brachionidae with a new variety of *B. forficula* (*B. forficula keralaiensis)*, having the morphological resemblances with both *B. forficula* and *B. havanaensis* and a new record of *Dipleuchlanis propatula* from India. Nair and Nayar (1971) studied rotifers of Irinjalakuda and added more species to the fauna of Kerala. However, the systematic studies of rotifers from brackish water habitats of Kerala have received very little attention, eventhough they are the dominant plankton of the backwaters. Studies of Harikrishnan (1993), Anuradha Rammohan (1996) and George Thomas (1996) recorded the availability and abundance of rotifers in the brackish water regions of Kerala. Harikrishnan (1993) had reported *B. donneri* and *B. plicatilis* for the first time from the State. Gopakumar (1998) studied the rotifers in the estuaries of Kerala. He documented thirty species of rotifers and recorded the presence of *B. plicatilis* 'S' type (= *B. rotundiformis*) for the first time from the Indian subcontinent.

It is evident from the above that the rotifer fauna of Kerala had received very little attention when compared to those from other parts of India, where continual efforts are being made to study them. The studies of Nayar and Nair (1969), Nair and Nayar (1971), Harikrishnan (1993) and Gopakumar (1998) revealed that the species belonging to the family Brachionidae under the order Ploimida dominated the rotifer fauna of Kerala but these works have contributed very little to the systematic or taxonomic studies of rotifers of Southern Kerala. Furthermore, during the course of this work, a need for more complete descriptions and illustrations was felt. Many of the recent works give only brief generic and specific diagnoses making it difficult to comprehend this

subject and make an accurate evaluation. Therefore, an attempt is made here to give a systematic account of species belonging to the family Brachionidae by including all available synonyms / subspecies / forms occurring in different hydrographic conditions as part of the present study. Further, salient features of each species together with illustrations are also presented anticipating that it would be of help to future workers.

MATERIAL AND METHODS

Plankton samples were collected from Veli-Aakulam and Poonthura estuaries during 2000-2001. The centres of sample collection are shown in Figures 1 & 2; Pl. 1 & 2. The samples were collected by horizontal hauls using plankton net of 32 cm mouth diameter. The mesh size of the net used was 70 μm. Samples were immediately preserved in 4% formaldehyde. The sorting and identification of rotifers were done with a stereo-dissecting microscope. All the illustrations given are camera lucida drawings made with the aid of a compound microscope. The various morphometric measurements taken are shown in Fig. 3.

The key used in separating different classes of phylum Rotifera upto orders is that of Edmondson (1959). The key in separating the different families is that of Koste (1978) and Koste and Shiel (1987). For genera and species no single key can be cited as effective but the works of Edmondson (1959), Koste (1978), Koste and Shiel (1987), Koste and Poltz (1987), Sudzuki (1987, 1999), Bathish (1992) and Sharma *et al.* (1992) served well in delineating them properly. The forma (f.) mentioned in the keys denotes only the respective morph that represented in the collection and it did not have any taxonomic significance, because in earlier literature like Bathish (1992) the forms are considered as subspecies of the respective taxon. However, the continual review of the later workers showed that most of the rotifers exhibit cyclomorphosis. Therefore, the recent workers followed a detailed

nomenclature where the respective taxon and their ecomorph were also given (Koste and Shiel, 1989; Nogrady *et al.*, 1993).

A combination of both Koste and Shiel (1987) and Sudzuki's (1999) classification keys were followed in the present account with slight modification since mental margin (ventral margin or pectoral margin) was also one of the important aspects of the key for delineating the species properly, especially in the case of sympatric sibling species complex. However, Sudzuki's (1999) monograph was more useful as in this infraspecific variability (forms/subspecies) were recorded in detail. Similarly, in the present account, rotifers were classified under the phylum ROTIFERA, rather than a class under the phylum 'Aschelminthes' because the recent workers such as Nogrady *et al.* (1993) and Segers (1995, 2002) have assigned the rotifers from the 'class Rotifera to phylum Rotifera'. Likewise, the name 'Rotifera' was used in the present account instead of 'Rotatoria' and this name are now widely accepted in literature (based on the nomenclature preference).

Of the seventeen families of the order Ploimida only ten families are represented in the present collection, they are: i) Epiphanidae, ii) Brachionidae, iii) Euchlanidae, iv) Mytilinidae, v) Trichotriidae, vi) Colurellidae, vii) Lecanidae, viii) Notommatidae, xi) Synchaetidae, and x). Asplanchnidae. Of the seven families of the order Floscullariacea, only three families are represented in the present collection; they are: i) Testudinellidae, ii) Hexarthridae and iii) Filiniidae. Since systematics was not the only aspect of the present study, the species belonging to the family Brachionidae alone have been selected for the systematic account in detail, as they are the ones cultured and used as first food for finfish and shellfish larviculture. Their dominance in plankton samples is another reason. However, all the identified rotifers are also given in the list of species. No attempt is made here to give a complete synonymy for any species; instead all available synonyms pertaining to each species are mentioned. Similarly, in species with three or more than

three forms a comparative morphometric data and diagnostic features are furnished.

The general distribution of each species is given under two heads: - in India and elsewhere; the later refers to the presently known distribution of each species on a global basis.

Though the earlier workers have amply illustrated most of the species, the specimens dealt with in this thesis are deposited in the reference collection of the Central Marine Fisheries Research Institute, Kochi.

RESULTS

LIST OF SPECIES

PHYLUM: ROTIFERA (Cuvier, 1798)

CLASS: MONOGONONTA Wesenberg-Lund, 1899*

ORDER: PLOIMIDA (Hudson and Gosse, 1889)

Family: Epiphanidae Harring, 1913

01. *Epiphanes macrourus* Barrois and Daday, 1894

Family: Brachionidae Ehrenberg, 1838

02. *Platyias quadricornis* (Ehrenberg, 1832)

03. *Platyias leloupi* Gillard, 1967

04. *Brachionus angularis* Gosse, 1851

B. angularis f. aestivus Skorikov, 1914

05. *Brachionus budapestinensis* Daday, 1885

06. *Brachionus calyciflorus* Pallas, 1766

B. calyciflorus f. typica Koste, 1978

B. calyciflorus f. heterospina Saksena, 1989

B. calyciflorus f. asymmetrica Koste, 1979

B. calyciflorus f. dorcas Gosse, 1851

B. calyciflorus f. anuraeformis Brehm, 1909*

B. calyciflorus f. forficula Rudescu, 1960

B. calyciflorus f. amphiceros Ehrenberg, 1838

B. calyciflorus f. monstruosa de Ridder, 1987

07. *Brachionus calyciflorus borgerti* Apstein, 1907

B. calyciflorus borgerti f. willeyi Apstein, 1907

B. calyciflorus borgerti f. brycei de Beauchamp, 1932

B. calyciflorus borgerti f. asymmetrica f. nov.

08. *Brachionus caudatus* Barrois and Daday, 1894

B. caudatus f. majusculus Ahlstrom, 1940

B. caudatus f. apsteini Ahlstrom, 1940

B. caudatus f. vulgatus Ahlstrom, 1940

B. caudatus f. personatus Ahlstrom, 1940

09. *Brachionus dichotomous reductus* Koste and Shiel, 1980

10. *Brachionus falcatus* Zacharias, 1898

B. falcatus f. lyratus Lemmerman, 1908*

B. falcatus f. β Apstein, 1907

B. falcatus f. hamatus Lemmerman, 1908*

11. *Brachionus patulus* (Müller, 1786)

12. *Brachionus kostei* Shiel, 1983

13. *Brachionus rubens* Ehrenberg, 1838

14. *Brachionus urceolaris* Muller, 1773

B. urceolaris f. irregularispina f. nov.

15. *Brachionus urceolaris nilsoni* Ahlstrom, 1940

16. *Brachionus havanaensis trahea* Murray, 1913

B. havanaensis trahea f. asymmetrica f. nov.

B. havanaensis trahea f. ahlstromi f. nov.

17. *Brachionus quadridentatus* Hermann, 1783

B. quadridentatus f. brevispina Ehrenberg, 1832

B. quadridentatus f. monospina Saksena and Kulkarni, 1986

B. quadridentatus f. divergens Tschugunoff, 1921

B. quadridentatus f. melheni Barrois and Daday, 1894

B. quadridentatus f. curvata Tschugunoff, 1921

18. *Brachionus quadridentatus mirabilis* Daday, 1897

19. *Brachionus plicatilis* Müller, 1786

B. plicatilis f. mülleri Ehrenberg, 1838

B. plicatilis f. hepatotomus Gosse, 1851

B. plicatilis f. decemcornis Fadeew, 1925

B. plicatilis f. ovalis f. nov.

20. *Brachionus murray* Murray, 1913

B. murray f. ecornis Fadeew, 1925

B. murray f. divergispina f. nov.

21. *Brachionus rotundiformis* Tschugunoff, 1921

B. rotundiformis f. semicircularis f. nov.

22. *Keratella cochlearis* (Gosse, 1851)

K. cochlearis f. recurvispina Jägerskiöld, 1894*

K. cochlearis f. tecta Lauterborn, 1894

23. *Keratella tropica* (Apstein, 1907)

K. tropica f. aspina Fadeew, 1927

K. tropica f. asymmetrica Barrois and Daday, 1894

Family: Euchlanidae Ehrenberg, 1838

24. *Dipleuchlanis propatula* Gosse, 1887

Family: Mytilinidae Harring, 1913

25. *Mytilina ventralis* Ehrenberg, 1832

26. *Mytilina crassipes* Lucks, 1929

Family: Trichotridae Harring, 1913

27. *Trichotria tetractis* Ehrenberg, 1838

Family: Lepadellidae Harring, 1913

28. *Lepadella crestata* Vasisht and Bathish, 1971

29. *Lepadella ovalis* Müller, 1786

30. *Lepadella patella* Müller, 1773

Family: Lecanidae Remane, 1933

31. *Lecane leontina* (Turner, 1892)*

32. *Lecane ludwigi* (Eckstein, 1883)*

33. *Lecane luna* (Müller, 1776)

34. *Monostyla quadridentata* (Ehrenberg, 1832)

35. *Monostyla bulla* (Gosse, 1851)

Family: Notommatidae Hudson and Gosse, 1889

36. *Scaridium longicaudum* (Müller, 1786)

Family: Synchaetidae (Hudson and Gosse, 1886)

37. *Polyarthra vulgaris* Carlin, 1943

Family: Asplanchnidae Eckstein, 1883*

38. *Asplanchna brightwelli* Gosse, 1851

ORDER: FLOSCULARIACEA Harring, 1913

Family: Testudinellidae (Harring, 1913)

39. *Testudinella patina* Hermann, 1783

Family: Hexarthridae Edmondson, 1959

40. *Hexarthra intermedia* (Wierzejski, 1929)

Family: Filiniidae Pennak, 1953

41. *Filinia longiseta* (Zacharias, 1898)

42. *Filinia terminalis* (Plate, 1886)

43. *Filinia opolensis* (Zacharias, 1898)

44. *Filinia cornuta* (Weisse, 1847)*

* As given by Sudzuki (1999).

CLASSIFICATION AND DESCRIPTION OF SPECIES

PHYLUM: ROTIFERA (Cuvier, 1798)

The rotifers or wheel animalcules are microscopic, mostly free-living organisms with the anterior end formed into a ciliary apparatus, the corona,

with a differentiated pharynx containing movable pieces acting as jaws (mastax) and with a typical flame-bulb protonephridia.

KEY TO THE CLASSES OF ROTIFERA

01. Rotifers with paired generative organs.....2
    Rotifers with single generative organ, males present but mostly reduced. .....MONOGONONTA Wesenberg-Lund, 1899
02. Marine; corona not with two trochal discs, reduced; males fully developed.....SEISONIODEA Wesenberg-Lund, 1899*
    Fresh water; corona with two trochal discs, latter rarely reduced in some forms; males not known.....
    .....BDELLOIDEA (Hudson & Gosse, 1886)

* As given by Hyman (1951)

CLASS: MONOGONONTA Wesenberg-Lund, 1899

Swimming or sessile rotifers; with a single germovitellarium; males usually present, reduced, with one testis; mastax not ramate; lateral antennae present; foot present or absent, when present with two toes or without toes.

KEY TO THE ORDERS OF MONOGONONTA

01. Free swimming, never fixed; foot, when present, with toes.....
    .....PLOIMIDA (Hudson and Gosse, 1886)

    Adults rarely free swimming; foot, when present without toes.....2

02. Mastax malleoramate.....FLOSCULARIACEA Harring, 1913
    Mastax uncinate.....COLLOTHECACEA Harring, 1913

ORDER: PLOIMIDA (Hudson and Gosse, 1886)

Body shape vermiform, sacciform or dorso-ventrally flattened; corona not with trochal and circular circlets; foot normal with two toes, or reduced even absent in some; eyes present or absent, when present, one or two.

Of the seventeen families (Koste and Shiel, 1987) in this order, only family Brachionidae was selected for the systematic account in the present study.

FAMILY: BRACHIONIDAE Ehrenberg, 1832

Most of the forms heavily loricated; corona often with several dorso-transverse prominences bearing tufts of strong cilia, the pseudotroch, buccal field mostly supraoral, oblique or terminal; mouth funnel like, situated in buccal field. Foot present or absent; when present, with two toes. This family represents three genera in the present account. They are *Brachionus*, *Platyias* and *Keratella*.

KEY TO GENERA OF THE FAMILY BRACHIONIDAE

01. Foot present.....2
    Foot absent.....3
02. Foot jointed; two toes; eyes present or absent.....
    .....*Platyias* Harring, 1913
    Foot ringed, hose-shaped, retractile; two toes.....
    .....*Brachionus* Pallas, 1766
03. Dorsal plate without facets.....4
    Dorsal plate with facets; six anterior spines; 1, 2 or no posterior spines.....*Keratella* Bory de St. Vincent, 1822
04. With symmetrical anterior spines; or none.....5
    Asymmetrical anterior spines, unequal in length; single posterior spine, long and slender.....*Kellicottia* Ahlstrom, 1943

05. Lorica with six short anterior spines; dorsal plate with longitudinal striations, some species also with minute pustules.....
.....*Notholca* Hudson & Gosse, 1886

Lorica without spines, composed of two plates, dorsal arched, ventral almost flat, joined by flexible cuticle forming sulci.....
.....*Anuraeopsis* Lauterborn, 1900

Genus: *Platyias* Harring, 1913

Rotifers with illoricate, retractile head and strongly loricated body; dorsal anterior margin with two blunt median spines and two pointed spines of variable length at the posterior end; surface more or less granulated; foot jointed with three segments; corona as in *Brachionus*; dorsal antenna between the anterior spines; lateral antenna on the caudal part of dorsal lorica; eyes absent. The species live mostly on or about the surface of detritus, sediments or on putrid mud between littoral macrophytes. At present this genus contains two species, *P. quadricornis* and *P. leloupi* since Wulfert (1965) transferred *P. patulus* and *P. polyacanthus*, including variations from the genus *Platyias* to the genus *Brachionus*.

Type: *Noteus quadricornis* Ehrenberg, 1832

KEY TO SPECIES OF THE GENUS *PLATYIAS*

Lorica with a longer keel under the triangular frontal dorsal plaque.....
.....*P. leloupi* Gillard, 1967

No keel below trapezoid frontal plaque, but one pentagonal facet, and below this two hexagonal facets.....*P. quadricornis* (Ehrenberg, 1832)

Platyias quadricornis (Ehrenberg, 1832)

(Fig. 4)

Noteus quadricornis Ehrenberg, 1832, p. 143, Fig. 4: 5.

Platyias quadricornis Harring, 1913, p. 84; Pennak, 1953, p. 195, Fig. 120: N; Voigt, 1957, p. 148, T. 22: 4; Sudzuki, 1964, p. 99, pl. 5, Figs. 9-11; 1999, p. 55, pl. 38, Figs. 5 - 6; Nayar and Nair, 1969, p. 229; Dhanapathi, 1974, p. 369, pl. IV, Fig.1; Koste, 1978, T. 7, Figs. 1 - 2; Sharma, 1979, p. 229; Koste and Shiel, 1987, p. 969, Fig.11: 1; Kannan and Govindasamy, 1991, p. 41, pl. IV, Fig. 4; Bathish, 1992, p. 90, Fig. 76: 1 - 2.

Platyias quadricornis var. hexagonata Wulfert, 1956

Platyias quadricornis var. pentagona Wulfert, 1956

Material: Thirty-seven parthenogenetic females from Veli-Aakulam and Poonthura estuaries in Trivandrum, Kerala.

Description: Anterior dorsal margin with two stout median spines, some times rounded to at their tips; mental (pectoral or ventral) margin depressed towards the centre and serrate; lorica terminating posteriorly in two rather short and stout parallel spines; lorica with regular pattern of facets.

Measurements:

Total length of lorica	238-247 µm
Maximum width of lorica	173-178 µm
Length of antero-median spine	32-34 µm
Length of postero-lateral spine	25-65 µm

Distribution in India: Jammu & Kashmir, Punjab, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh and West Bengal

Elsewhere: Japan, New Zealand, Thailand, Singapore, Malaysia, Australia, Africa and U.S.A.

Comments: This species shows comparatively less variation, the most variable feature being the postero-lateral spines, which may be reduced or well developed.

Platyias leloupi Gillard, 1967

(Fig. 5)

Platyias quadricornis leloupi Gillard, 1967, p. 19, Fig. 4: 22.

Platyias leloupi Koste, 1974, p. 43; Koste, 1978, T. 7, Fig. 3a - g; Koste and Shiel, 1987, p. 968, Fig.11: 4; Sharma, 1987, p. 273, Fig. 20 - 21; Sarma, 1988, p. 265, Fig. 8.

Platyias leloupi latiscapulaaris Koste, 1974, p. 43.

Platyias leloupi var. aspina de Ridder, 1991, p. 473

Material: Six parthenogenetic females from Poonthura and Veli-Aakulam estuaries.

Description: Lorica firm, more or less circular, moderately compressed dorso-ventrally, tuberculate or stippled, composed of dorsal and ventral plates; antero-dorsal margin with two long spines curved outwards, acutely pointed; posterior spines long, pointed with widely separated bases; dorsal plates of lorica without polygonal markings, in some specimens the entire lorica stippled; mental margin rigid and depressed towards the centre; foot two segments with two toes.

Measurements:

Total length of lorica	352-429 µm
Maximum width of lorica	225-278 µm
Length of antero-median spine	65-78 µm
Length of posterior spine length	98-107 µm

Distribution in India: Maharashtra, Haryana, Kerala and Andhra Pradesh.

Elsewhere: Brazil, Africa, Sri Lanka and S. America.

Comments: *P. leloupi* is a less variable species when compared to other rotifers and the most variable feature being the postero-lateral spine length.

Genus: ***Brachionus*** Pallas, 1766

Brachionus is the oldest valid generic name in the phylum ROTIFERA. Heavily loricated forms; lorica broad and covers the trunk completely; may be one piece when it continues around the body or two pieces united through flexible cuticle; dorsal plate arched, ornamented in some, whereas ventral plate relatively flat; lorica in some species stippled, antero-dorsal edge always with even number of spines (two, four, six etc.); antero-ventral (= mental margin or pectoral margin) rigid or flexible but may be wavy or smooth with 'v' or 'u' shaped notch; with or without spines; postero-lateral spines present or absent depending upon the species and may seasonally appear or disappear even in the same species; postero-median spines (caudal spines) mostly present and flank the foot, anterior portion of the body projects from lorica in the form of coronal disc which bears a circlet of cilia and three prominences covered with cilia of larger size; foot long, slender, annulated, retractile, with two toes, with no spur or spine, highly contractile and projects from the postero-ventral edge of lorica, imparting a subsquare aperture in dorsal plate and a large usually oval aperture in the ventral plate; foot sheath seldom present; large mastax with malleate trophy; single germovitellarium; males of most species known.

Most species are thermophilic. Global distribution shows the greatest number of species in subtropical and tropical areas (Green, 1972b). The species belonging to this genus are highly polymorphic and they are not generally reported from acid waters but some species thrive well in saline and alkaline waters. This is by far the best-known genus from India and it embraces twenty-one species with more than eleven forms and three subspecies. However, only fourteen species with four subspecies are represented in the present study under this genus.

Type: *Brachionus calyciflorus* Pallas, 1766

CLASSIFICATION OF SPECIES BELONGING TO THE GENUS *BRACHIONUS*

In the genus *Brachionus*, the following characters are regarded by Ahlstrom (1940) and Gillard (1948) as the specific taxonomically important ones: a) number of the occipital spines (six, four, two, wanting); b) length of the anterior spine and position of the longest spine; c) basal plate (present or absent); d) mental (pectoral or ventral) margin (flexible, rigid, with spine like protuberances with median sinus, irregularly elevated towards centre); e) posterior spines (present or absent, if present, the direction of development); f) extension of the dorsal plate (over or not overhanging on the foot opening, with or without knee like swellings on the inner side near the base); g) foot sheath (present or absent); h) ornamentation of the lorica; i) lateral view of the posterior part of the lorica (truncated or pointed); j) shape of the occipital spines (saw-toothed or not); k) lorica (divided or undivided into dorsal and ventral plates); l) foot opening (with or without anchor-shaped spines); m) length of the anterior median spines. According to the Sudzuki's opinion, all of the above criteria have not always the same value as taxonomic characters for the species; of all, **the features of the occipital spines and the mental (ventral or pectoral) margin are the most important**. Based on the morphological characters especially the number of occipital spines, Ruttner-Kolisko (1974) divided the genus into groups (= Formenkreis) i.e., clusters of similar and recognized related species ranked together as *angularis* group, *urceolaris* group etc. Later on, Koste (1979) and Sudzuki (1999) have remodified this division and the species groups within the genus are: *patulus* group, *pala* (= *calyciflorus*) group, *plicatilis* group, *caudatus* group, *quadridentatus* group, *angularis* group, *forficula* group, *budapestinensis* group, *pterodinoides* group, *falcatus* group, *urceolaris* group and *sessilis* group. However, under each species a number of forms / subspecies occurred and hence I have adopted a combination of the keys of Koste and Shiel (1987) and Sudzuki (1999) with certain modification for describing the taxa represented in the present study.

KEY TO THE SPECIES GROUPS OF GENUS *BRACHIONUS*

01. Pectoral margin with spines; (>2 pairs).....*patulus* or *donneri* group
    Pectoral margin without spines.....2
02. Lorica soft, sac formed; dorsal and ventral plates not distinguishable.....3
    Lorica stiff, vase shaped; dorsal and ventral plates distinguishable.....4
03. Occipital spines usually two pairs.....*pala* group
    Occipital spines usually three pairs; pectoral margin usually four lobed.....
    .....*plicatilis* group
04. Dorso-posterior plates double-deckered.....5
    Dorso-posterior plates other wise.....6
05. Dorso-caudal extension (above the foot opening plate) weakly develop....
    .....*caudatus* group
    Dorso-caudal extension (above the foot opening plate) well developed.....
    .....*quadridentatus* group
06. Occipital spines present or absent, if present it is obliterated.....
    .....*angularis* group
    Occipital spines present and well developed.....7
07. Occipital spines usually two pairs.....8
    Occipital spines usually three pair.....9
08. Posterior spines long.....*forficula* group
    Posterior spines absent (usually).....*budapestinensis* group
09. Longer occipital spines present.....*falcatus* group
    Longer occipital spines absent.....10
10. Foot opening (position) ventral.....*pterodinoides* group
    Foot opening (position) terminal.....11
11. Intermediate spines well developed.....*urceolaris* group
    Intermediate spines present or absent, if present it is obliterated.....
    .....*sessilis* group

KEY TO THE SPECIES / INFRASPECIES OF *ANGULARIS* GROUP

A total of 13 species and eight infraspecies are listed under the *angularis* group by Sudzuki (1999) in his monograph entitled '*An Approach to the Identification of Common Rotifers*'. However, in the present study only one

species (*B. angularis*) and one ecomorph were recorded and therefore, the key given below is chiefly on species recorded in the Indian waters under this group.

01. Posterior projections incurved .....*angularis* Gosse, 1851
    Posterior projections otherwise.....2
02. Occipital margin with toothed notch; posterior projections parallel-sided...
    .....*bidens* Plate, 1886
    Occipital margin without toothed notch; posterior projections strongly incurved or fused.....*f. aestivus* Skorikov, 1914

Brachionus angularis Gosse, 1851

(Figs. 6-11)

Brachionus angularis Gosse, 1851, p. 203; Hudson and Gosse, 1889, pl. 27, Fig. 4, pl. 30, Fig. 9; Ahlstrom, 1940, T.fig.1; Sudzuki, 1955, Text. Fig. 1; 1964, p. 96, pl. 2, Figs. 1 - 18; 1999, p. 22, pl. 5, Fig. 1, p. 46, pl. 26, Fig. 5; Voigt, 1957, p.155, T.19: 2, 3; Arora, 1963, p.115, Fig. 5; Nayar, 1968, p. 171, Figs. 4 - 8; Nayar and Nair, 1969, p. 226; Nair and Nayar, 1971, p. 46, Fig. 12; Dhanapathi, 1974, p. 366; Sharma, 1980a, p. 227, Figs. 2 - 3; 1980b, p. 251, Figs. 3 - 4; 1983, p. 33, Figs. 10 - 13; Kannan and Govindasamy, 1991, p. 39, pl. II, Fig. 2; Bathish, 1992, p. 87, Fig. 72; Singh and Shakuntala Pandey, 1993, p. 140, Fig. 1.

Brachionus papuana Daday, 1897, p. 142, Fig. 9

Brachionus angularis f. aestivus Skorikov, 1914

Brachionus angularis f. apicata Tschugunoff, 1921, pl. 1, Figs. 1 - 8

Brachionus angularis f. pseudodolabratus Ahlstrom, 1940, p. 402, Fig. 3e.

Brachionus angularis f. culosa Wulfert, 1956, p. 402, Figs. 3a - c

Brachionus angularis var.irregularis Wulfert, 1956, p. 402, Fig. 3e

Brachionus angularis var. bidens Arora, 1963, p.115

Brachionus angularis angularis Koste and Shiel, 1987, p. 993, Figs. 22:1, 2, 3a - h

Brachionus angularis orientalis Sudzuki, 1991, pl. 3 - 4

Brachionus angularis f. daitojimensis Sudzuki, 1992, pl. 1, Figs. 1 - 7

Material: Several parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica firm, lightly or heavily stippled, divided into dorsal and ventral plates; antero-dorsal margin with two median spines, laterals and intermediates absent; mental margin rather undulate, somewhat elevated without a central notch; foot opening with a 'u' shaped aperture and two short bluntly pointed protuberances in the ventral plate, relatively close together and convergent.

Measurements:

Total length of lorica	80-116 µm
Maximum width of lorica	76-96 µm
Length of antero-median spine	7-11 µm
Size of resting egg	98/64 µm
Size of subitaneous egg	67/47 µm
Maximum width-total length ratio	0.74-0.84

Distribution in India: Punjab, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and Bihar.

Elsewhere: Australia, Germany, Malaysia, Singapore, Thailand, Nepal, Tibet, Japan, Tasmania and Argentina.

Comments: *B angularis* is one of the most variable species of *Brachionus*. Many forms are reported worldwide. However, in the present collection a small morph of this species was observed (Figs.9 - 11). The important identification characters and the measurements of this morph are as follows:

Brachionus angularis f. aestivus Skorikov, 1914

(Figs: 9-11)

Description: Small in size; not so elevated mental margin with little undulation; caudal protuberances so strongly bent inwards or close together that basely observable from the dorsal side; the outline of the lorica of the specimens collected from Veli-Aakulam estuary is somewhat circular (Figs.9 -11) and the anterior median spines bending towards the middle. The specimens depicted by Ahlstrom (1940, pl. 5,

Figs.12 - 13) from Sholavaram Lake, Madras; Nayar (1968, p. 171, Figs.7 - 8) from Rajasthan and Bathish (1992, p. 87, Fig.72) from Punjab, India could belong to this form.

Measurements:

Total length of lorica	80-84 µm
Maximum width of lorica	73-76 µm
Size of egg	64/42 µm
Maximum width -total length ratio	0.93

KEY TO THE SPECIES / INFRASPECIES OF *BUDAPESTINENSIS* GROUP

01. Occipital spines two pairs; pectoral margin two lobed; lorica surface with geometrical pattern.....*budapestinensis* Daday, 1885

Occipital spines two pairs; pectoral margin undulated; lorica surface with or without ornamentation .....*dimidiatus* Bryce, 1931

Brachionus budapestinensis Daday, 1885

(Figs: 12 - 13)

Brachionus budapestinensis Daday, 1885, p. 131, 211, Fig. 11: 1 - 4, 8, 10; Sudzuki, 1955, p. 123, Figs. 3 - 4; 1964, p. 99, pl. 5, Figs. 1 - 8; 1999, p. 49, pl. 32, Fig. 5; Koste, 1978, T. 12, Figs. 4a - g; 1979, p. 240, Fig. 6; Sharma, 1980b, p. 250, Fig. 7; 1983, p. 33, Fig. 26; Koste and Shiel, 1987, p. 988 - 989, Fig. 20: 4a - g; Bathish, 1992, p. 87, Fig. 71: 1 - 2.

Brachionus punctatus Hempel, 1896, p. 310 - 317; Voigt, 1957, pl. 21, Figs. 8c - d

Brachionus budapestinensis var. punctatus Arora, 1963, p. 118, Fig. 1.

Material: Several of parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica firm, oval, divided into dorsal and ventral plates; ornamented with pattern of cuticular ridges on both dorsal and ventral plates; antero-dorsal margin with four spines; median pair longer than

laterals and their distal end curved ventrally; posterior spines wanting, mental margin nearly straight; foot opening more or less rounded.

Measurements:

Total length of lorica	121-126 µm
Maximum width of lorica	87-100 µm
Length of antero-median spine	27-35 µm
Length of lateral spine	20-26 µm

Distribution in India: Punjab, Maharashtra, Kerala, West Bengal and Assam.

Elsewhere: Germany, Bohemia, Sweden, Russia, Australia, Japan and Sri Lanka.

Comments: This species does not show much morph variations.

KEY TO THE SPECIES / INFRASPECIES OF *CALYCIFLORUS* GROUP

01. Occipital spines 3 in number.....*tridens* Hood, 1893
    Occipital spines 2 pairs.....2
02. Occipital median spines with serration (near the base); pectoral (mental) - margin flanked with two small spines..... *borgerti*.....12
    Occipital median spines without serration; mental margin without spines .....*calyciflorus*.....3
03. Posterior elongation (calyx-shaped); occipital spines funnel shaped..... .....*f. spinus* Sudzuki, 1992
    Posterior elongation; occipital spines are not as above.....4
04. Postero-median spines present; some times rudimentary.....5
    Postero-median spines present; well developed.....6
05. Postero-lateral spines, two and asymmetrical...*f. asymmetrica* Koste, 1979
    Single postero-lateral spine.....*f. heterospina* Saksena, 1989
06. Postero-median spines short and thick.....*f. taketomiensis* Sudzuki, 1992
    Postero-median spines otherwise.....7

07. Occipital median spines length - body width ratio>1/3.....8

Occipital median spines length - body length ratio<1/3.....9

08. Posterior spines absent.....*f. dorcas* Gosse, 1851

Posterior spines present.....*f. dorcas spinosus* Wierzejski, 1891

09. Posterior spines - frontal spines ratio greater than two.....10

Posterior spines - frontal spines ratio less than one.....11

10. Posterior spines incurved.....*f. forficula* Rudescu, 1960

Posterior spines otherwise.....*f. monstruosa* de Ridder, 1987

11. Body slender.....*f. anuraeformis* Brehm, 1909*

Body otherwise.....*f. amphiceros* Ehrenberg, 1838

12. Posterior spines absent.....13

Posterior spines present.....14

13. Postero-median spines short.....*f. brycei* de Beauchamp, 1932

Postero-median spines long and symmetrical.....*f. willeyi* Ahlstrom, 1943

14. Poster-lateral spines asymmetrical.....*f. asymmetrica* f. nov.

Postero-lateral spines otherwise.....*f. borgerti* Apstein, 1907

*As given by Koste, 1978

Brachionus calyciflorus Pallas, 1766

(Figs: 14 – 21)

Brachionus calyciflorus Pallas, 1766, p. 93; Harring, 1913, p. 19; Voigt, 1957, p. 140, T. 19: 8; Sudzuki, 1962, p. 51; 1964, p. 100, pl. 6, Figs. 1 - 17; 1999, p. 25, pl. 8, Fig. 8; Arora, 1966, p. 3, T. fig.1a - d; Nayar and Nair, 1969, p. 65; Nair and Nayar, 1971, p. 45, Figs. 6 - 7; Dhanapathi, 1974, p. 364; Koste, 1978, T. 12, Fig. a - f; 1979, p. 239, Fig.1; Sharma, 1983, p. 34, Fig. 40; Koste and Poltz, 1987, p. 197 - 198, Abb. 3a - j; 4a - f; Kannan and Govindasamy, 1991, p. 39, pl. II, Figs. 3 - 4; Bathish, 1992, p. 79, Fig. 64: 1 - 3; Sharma *et al.*, 1992, p. 441 - 142, Fig. 19; Singh and Shakuntala Pandey, 1993, p. 40, Fig. 3.

Brachionus pala Ehrenberg, 1838, pl. 63, Fig. 1; Hudson and Gosse, 1886, pl. 27, Fig. 3, pl. 28, Figs. 3 - 4

Brachionus amphiceros Ehrenberg, 1838, p. 511 - 512, pl. 63, Fig. 2.

Brachionus con Gosse 1851, p. 203.

Brachionus dorcas Gosse 1851, p. 203; Hudson and Gosse 1886, pl. 28, Fig. 4

Brachionus deciepiens Plate, 1886, p. 73.

Brachionus dorcas var. spinosus Wierzejski, 1891, Fig.14

Brachionus tridens Hood, 1893, p. 283, pl. 12, Fig. 3

Brachionus pala var. anuraeiformis Brehm, 1909, p. 210, Fig. 1.

Brachionus pala dimidiates de Beauchamp, 1932, T. fig. 2a

Brachionus pala var. inermis de Beauchamp, 1932, p.237, Fig.2d - e

Brachionus pala var. quartaris de Beauchamp, 1932, p. 161, Fig. 1d

Brachionus calyciflorus var. amphiceros f. forficula Rudescu, 1960, p. 459 - 460, Fig. 8

Brachionus calyciflorus f. typica Koste, 1978, T. Fig.1a; Koste and Shiel, 1987, p. 990, Fig.21: 1c

Brachionus calyciflorus f. monstruosa de Ridder, 1987, p. 129, Fig .2

Brachionus calyciflorus f. asymmetrica Koste, 1979, Fig.21: 2d, e.

Brachionus calyciflorus f. spinus Sudzuki, 1992, p. 22, pl. 5, Fig. 3

Material: Several parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica flexible, oval to subcircular, not separated into dorsal and ventral plates; body slightly compressed dorso-ventrally, anterior dorsal margin with four broad based spines of variable length, medians longer than laterals; mental margin flexible, usually somewhat elevated with shallow 'v' or 'u' shaped notch; posterior spines may or may not be present.

Measurements:

Total length of lorica	224-380 µm
Maximum width of lorica	121-242 µm
Length of antero-median spine	51-52 µm
Length of lateral spine	30-35 µm
Maximum width-total length ratio	0.72-0.73

Distribution in India: Jammu & Kashmir, Punjab, Haryana, Bihar, Rajasthan, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal, Assam, Meghalya and Manipur.

Elsewhere: Australia, Japan, Nepal, Sri Lanka, Thailand, Nigeria, Malaysia, Singapore, North America, South America and Britain.

Comments: *B. calyciflorus* is an extremely variable species. The cyclomorphs of this species has been extensively studied by a number of workers. The most illustrative field observations regarding forms or varieties in *B. calyciflorus* come from Dieffenbach & Sachse (1911), Hartmann (1920), Wesenberg-Lund (1930), Ahlstrom (1933), Nayar (1964, 1965a), Arora (1966c) and Saksena and Sharma (1981c). Investigations on morph variations in laboratory cultures come from de Beauchamp (1952a and b). Yet there is difference of opinion on the systematics of this polymorphic species. Similarly, because of this polymorphism, an extensive synonymy of this species was observed in the literature. Different workers from different geographical areas have reported many ecomorphs of this species. Similarly, a variety of ecomorphs observed in the plankton samples during the period study and is listed below with their measurements and important diagnostic features.

Form 1: *Brachionus calyciflorus f. typica* Koste, 1978 (Fig. 14)
Form 2: *B. calyciflorus f. heterospina Saksena*, 1989 (Fig. 15)
Form 3: *B. calyciflorus f. asymmetrica Koste*, 1979 (Fig. 16)
Form 4: *B. calyciflorus f. dorcas* Gosse, 1851 (Fig. 17)
Form 5: *B. calyciflorus f. anuraeformis* Brehm, 1909 (Fig. 18)
Form 6: *B. calyciflorus f. forficula* Rudescu, 1960 (Fig. 19)
Form 7: *B. calyciflorus f. amphiceros* Ehrenberg, 1838 (Fig. 20)
Form 8: *B. calyciflorus f. monstruosa* de Ridder, 1987 (Fig.21)

	Diagnosis
Form 1	Median occipital spines slightly longer than lateral ones; postero-lateral spines absent
Form 2	Median occipital spines as above; single postero-lateral spine
Form 3	Median occipital spines as above; postero-lateral spines unequal in length
Form 4	Median occipital spines much longer than laterals; postero-lateral spines absent
Form 5	Median occipital spines not as above; posterior-occipital spines ratio less than one; body slender

Form 6	Median occipital spines slightly longer than laterals; posterior-occipital spine ratio is greater than one; postero-lateral spines incurved
Form 7	Median occipital spines and postero-lateral spines are same as Form 6; but postero-lateral spines are shorter than the former.
Form 8	Occipital spines same as above; very long postero-lateral spines

Measurements (μ m)	Form 1	Form 2	Form 3	Form 4	Form 5	Form 6	Form 7	Form 8
Lorica length	264	260	243	381	277	294	255	260
Lorica width	190	173	156	242	190	156	121	104
Occipital-median spine length	52	52	40	121	47	52	52	52
Occipital-lateral spine length	35	35	33	69	30	78	43	52
Postero-lateral spine length	-	21	13/24	-	34	147	87	52
Postero-median spine length	35	35	13	52	11	69	52	121
Maximum length-width ratio	0.72	0.64	0.64	0.64	0.69	0.53	0.45	0.40

Brachionus calyciflorus borgerti Apstein, 1907

(Figs.22 - 27)

Brachionus amphiceros var. borgerti Apstein, 1907, p. 211, Figs. G, H; Sudzuki, 1964, p. 1- 4; 1999, p.1-34.

Brachionus pala var. willeyi Apstein, 1907, p. 213, Fig. 1; Sudzuki, 1999, p. 25, pl. 8, Fig. 9.

Brachionus calyciflorus var. brycei de Beauchamp, 1932, p.161, Fig.1d; Arora, 1966, p. 3, T. fig.1e

Brachionus calyciflorus var. hymani Dhanapathi, 1974, p. 364 - 365, pl. 2, Figs. 3 - 4

Material: Several parthenogenetic females from Veli-Aakulam estuary.

Description: Lorica flexible, smooth and not separated into a dorsal and ventral plates; anterior dorsal margin with broad based stout spines with round tips; saw tooth like prominent outward extension are present from the base of the median spines; median spines are longer than laterals; mental (ventral) margin having a 'v' shaped median sinus, flanked on either side by two short spine like process; posterior spines may or may not be present; if present, postero-lateral and postero-median spines flanking on the foot opening.

Measurements:

Total length of the lorica	294-415 µm
Maximum width of lorica	173-278 µm
Antero-median spine length	60-87 µm
Antero-lateral spines length	43-65 µm
Postero-lateral spine length	43-60 µm
Postero-median spine length	13-30 µm
Antero-ventral spine length	22-39 µm
Maximum width -total length ratio	0.58-0.69

Distribution in India: Punjab, Kerala, Andhra Pradesh and West Bengal.

Elsewhere: Sri Lanka, Australia and Japan.

Comments: A variety of morphs were collected from the Veli-Aakulam estuary. All these forms are different from *B. calyciflorus* Pallas, 1766 in the following characteristics: i) rather stiff mental margin with a pair of triangular median projections, ii) accessory swelling at the outer base of occipital median spine; comparatively large size-groups, iii) anterior median spines deeply curved inwardly, forming a distinct narrow 'v' shape. One of the interesting observations in all these morphs is the presence of mental margin spine, which is constant whereas, in *B. calyciflorus* the mental margin shows variations, and lack of spines. According to Sudzuki (1998), the shape and variations in the mental margin are also important criteria for the identification of a species. Furthermore, during the experimental studies of *B. calyciflorus* (Pallas) at different temperatures, feed types and salinities, almost all the

common ecomorphs (*f. typica*, *f. anuraeiformis*, *f. amphiceros*) of this taxon were observed in the laboratory. However, none of the forms of *borgerti* was observed in the cultures maintained in the laboratory. Therefore, based on the above mentioned facts it seems that the present taxon might be a subspecies or a distinct variety of *calyciflorus* rather than an ecomorph of Pallas's *calyciflorus*.

The important diagnostic characters and measurements of the collected morphs in the present study are as follows:

Form 1: *B. calyciflorus borgerti f. brycei* de Beauchamp, 1932 (Fig. 22)

Form 2: *B. calyciflorus borgerti f. asymmetrica* f. nov. (Fig. 23)

Form 3: *B. calyciflorus borgerti f. willeyi* Apstein, 1907 (Fig. 25 & 26)

	Diagnosis
Form 1	Postero-median spines short; may or may not be curved inwards; postero-lateral spines absent
Form 2	Postero-lateral spines present; unequal in length
Form 3	Postero-median spines long and symmetrical; postero-lateral spines absent or if present rudimentary

Measurements (μm)	Form 1	Form 2	Form 3
Lorica length	346	381	407-415
Lorica width	208	242	242-278
Occipital-Median spine length	65	87	86-87
Occipital-lateral spine length	52	42	52-65
Postero-lateral spine length	-	42/32	-
Postero-median spine length	-	27	54-57
Mental margin spine length	30	21	30-39
Maximum length-width ratio	0.60	0.64	0.42-0.58

KEY TO THE SPECIES / INFRASPECIES OF *CAUDATUS* GROUP

01. Dorso-caudal extension sub-square; Occipital spines > one pair; inter-medians present; rudimentary.....*dichotomus reductus* Koste&Shiel, 1980

Dorso-caudal extension triangular.....2

02. Occipital spines >one pair; inter-median spines present.....3

Occipital spines usually one pair; intermediate spines usually absent.....4

03. Posterior spines length / body width>1/2.....*f. personatus* Ahlstrom, 1940

Posterior spines length / body width <1/2.....*f. insuetus* Ahlstrom, 1940

04. Posterior spines length / body width>1/2.....*f. majusculus* Ahlstrom, 1940

Posterior spines length / body width <1/2.....5

05. Posterior spines length / body width <1/2 -1/3.....*f. apsteini* Ahlstrom, 1940

Posterior spines length / body width < ½ ; Occipital lateral spine usually absent.....*f. vulgatus* Ahlstrom, 1940

Brachionus caudatus Barrois and Daday, 1894

(Figs. 28 - 32)

Brachionus caudatus Barrois and Daday, 1894, p. 232, pl. 7, Figs. 9, 10, 13; Voigt, 1957, p. 156, T. 20: 18; Arora, 1963, p. 115, Figs. 3; Dhanapathi, 1974, p. 363, pl. III, Fig. 1; Koste, 1978, T. 13, Figs. 8 - 10, 15, 18 - 24; 1979, p. 242, Fig. 12; Sharma, 1980a, p. 227, Figs. 5 - 6; 1980b, p. 250, Figs. 8 - 9; 1983, p. 34, Figs. 27 - 39; Koste and Shiel, 1987, p. 993, Figs. 22: 4b, 23: 1, 2; Kannan and Govindasamy, 1991, p. 39, pl. II, Fig. 6; Sharma *et al.*, 1992, p. 442, Figs. 21 - 24; Bathish, 1992, p. 83, Figs. 67: 1 - 5; Singh and Shakuntala Pandey, 1993, p. 140, Figs. 4-5; Sudzuki,1999, p. 24, pl. 7, Figs. 5 - 7, pl. 1 - 7, p. 51, pl. 34, Figs.1 - 4.

Brachionus angularis var. caudatus Murray, 1913, pl. 13, Fig. 46

Brachionus angularis caudatus Carlin, 1935, Fig. 4

Brachionus angularis var. aculeatus Hauer, 1937, Fig.1a

Brachionus angularis var. aculeatus f. lateralis Hauer, 1937, Fig. 1b

Brachionus caudatus f. provectus Ahlstrom, 1940, pl. 6.Figs. 1-2

Brachionus caudatus f. vulgatus Ahlstrom, 1940, pl. 6, Figs. 6, 8

Brachionus caudatus f. apsteini Ahlstrom, 1940, pl. 6, Fig. 5

Brachionus caudatus f. majusculus Ahlstrom, 1940, pl. 6, Fig. 7

Brachionus caudatus f. insuetus Ahlstrom, 1940, pl. 6, Figs. 3 - 4

Brachionus caudatus f. austrogenitus Ahlstrom, 1940, pl. 7, Figs. 3-4; Hauer, 1953, p. 163 - 164, Figs. 3d - e

Brachionus caudatus var. personatus Ahlstrom, 1940, pl. 7, Figs. 1 - 2

Brachionus caudatus apsteini Sudzuki, 1991, pl. 5, Fig. 2

Brachionus caudatus singapurensis Sudzuki, 1991, pl. 5, Figs. 6 - 9

Material: several parthenogenetic females from Poonthura estuary.

Description: Lorica firm, stippled, with a pattern of cuticular ridges; divided into dorsal and ventral plates, somewhat compressed dorso-ventrally; anterior-dorsal margin with two median spines, separated by 'v'-shaped or 'u'-shaped notch; laterals mostly longer than medians; intermediate spines reduced or wanting; rarely all six occipital spines present; mental margin rigid, slightly elevated, at times undulate, with a shallow median sinus; lorica terminating in two stout posterior spines, separated at their bases by about half width of the lorica, usually divergent and strongly flexed ventrally; foot opening between bases of posterior spines, with a 'u'-shaped aperture in the ventral plate; dorsal plate overhanging foot opening with a triangular extension of lorica.

Measurements:

Total length of lorica	103-225 µm
Maximum width of lorica	82-138 µm
Antero-dorsal spine length	13-24 µm
Antero-lateral spine length	7-9 µm
Postero-lateral spine length	17-87 µm
Maximum width-total length ratio	0.53-0.85

Distribution in India: Punjab, Rajasthan, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, Bihar and Meghalaya.

Elsewhere: Poland, Syria, Africa, Java, South America and Australia.

Comments: This species is restricted to the tropical waters unlike most *Brachionus* species. The posterior spines vary from little developed to well developed and even asymmetrically developed. Among the anterior spines, the intermediate spine may or may not be present.

The forms observed in the present collection are given below with their important diagnostic characters and measurements.

Form 1: *B. caudatus f. majusculus* Ahlstrom, 1940 (Fig. 28)

Form 2: *B. caudatus f. apsteini* Ahlstrom, 1940 (Fig. 29 & 31)

Form 3: *B. caudatus f. vulgatus* Ahlstrom, 1940 (Fig. 30)

Form 4: *B. caudatus f. personstus* Ahlstrom, 1940 (Fig. 32)

Measurements (μm)	Form 1	Form 2	Form 3	Form 4
Lorica length	156	138	104	160
Lorica width	78	95	88	87
Median spine length	22	13	5	9
Antero-lateral spine length	22	9	-	4
Antero-intermediate spine length	-	-	-	20
Postero-median spine length	53	20	43	44
Maximum length-width ratio	0.50	0.69	0.86	0.54
Posterior spine length-body width ratio	0.68	0.21	0.49	0.51

	Diagnosis
Form 1	Occipital spines two pairs; inter-medians absent; posterior spine length- body width ratio >1/2
Form 2	Occipital spines same as above; posterior spines length-body width ratio <1/2
Form 3	Occipital median spines only present
Form 4	Occipital spines three pairs; intermediate spines obliterated

Brachionus dichotomus reductus Koste and Shiel, 1980
(Figs. 33 - 35)

Brachionus dichotomus f. reductus Koste and Shiel, 1980a, p. 127-134, Figs. 2, 4, 6

Brachionus dichotomus reductus Koste and Shiel, 1987, p. 995, Fig. 23: 4a - l; Sanoamuang *et al.*, 1995, p. 41, Figs. 7 - 8; Sudzuki, 1999, p. 24, pl. 7, Fig. 7

Brachionus caudatus f. vulgatus Fernando and Nora, 1981, p. 211, Fig. 10

Material: Fifty-eight parthenogenetic females from Poonthura estuary.

Description: Lorica with long median anterior spines, which protrude as a 'v' shape; anterior lateral spines absent; anterior submedian spines

rudimentary, long caudal spines; lorica at the posterior end, overhanging the base of the foot opening.

Measurements:

Total length of lorica	125-144 µm
Width of the lorica	76-113 µm
Antero-median spine length	13-27 µm
Postero- median length	36-47 µm
Maximum width-total length] ratio	0.61-0.78
Size of egg	58/24 µm

Distribution in India: It is the first report from Kerala and India.

Elsewhere: Japan, Australia, Thailand, Malaysia and Singapore.

Comments: The specimens collected from Kerala estuaries are in conformity with Koste and Shiel's description morphologically, whereas they differ in size. The recorded size range of this species is about 145 -185 µm (including spines), whereas the present size range is 125 -168 µm only. This species was first described as a dwarf form of *B. dichotomus f. typica* from a locality of Australia (Koste and Shiel, 1980a) because of its morphological resemblances with *B. dichotomus dichotomus* Shephard, 1911. But in the present collection *B. dichotomus* was not represented. Further, Fernando and Nora (1981) has reported a species by the name *B. caudatus f. vulgatus* (p. 211, Fig.10) but this has a close similarity with *B. dichotomus reductus*. Therefore, Fernando's specimen may be *B. dichotomus reductus*.

KEY TO THE SUBSPECIES / INFRASPECIES OF *FALCATUS* GROUP

01. Longer occipital spines; median.....*gessneri* Hauer, 1959
    Longer occipital spines; intermediate .....*falcatus*.....2
02. Occipital intermediate spines parallel sided.....3
    Occipital intermediate spines divergent.....4
03. Postero-lateral spine length - body width ratio>1/2.....

.....*f. hamatus* Lemmerman, 1908*

Postero-lateral spine length - body width ratio<1/2.....

.....*f. reductus* Koste & Shiel 1983

04. Posterior spines incurved.....*f. β* Apstein, 1907

Posterior spines otherwise.....*f. lyratus* Lemmerman, 1908*

* Quoted from Suzuki, 1999

Brachionus falcatus Zacharias, 1898

(Figs. 36 - 39)

Brachionus falcatus Zacharias, 1898, p. 401-403, Figs. 28-35; Ahlstrom, 1940, p.164, Fig.10: 1 - 2; Sudzuki, 1956, p. 416, Fig.1; 1964, p. 103, pl. 9, Figs. 1 - 7; 1999, p. 27, pl. 10, Figs. 6-8; Voigt, 1957, p. 151, T. 21, Fig. 10; Dhanapathi, 1974, p. 351, pl. I, Fig. 3; Koste, 1978, T. 14, Fig. 14: 2; 1979, p. 251, Fig. 28; Sharma, 1980a, p. 228, Fig. 9; 1980b, p. 251, Fig. 11; 1983, p. 35, Fig. 19, 51; Koste and Shiel, 1983, p. 114, Fig. 3 a - f; 1987, p. 981, Fig. 17: 1a - e, g, h; Kannan and Govindasamy, 1991, p. 39, pl. II, Fig. 7; Sharma *et al.*, 1992, p. 443, Figs. 30 - 32; Bathish, 1992, p. 84, Figs. 68: 1 - 2; Shakuntala Pandey and Singh, 1993, p. 145, Fig. 1.

Brachionus falcatus f. hamatus Lemmerman, 1908, Fig. 33

Brachionus falcatus var. lyratus Lemmerman, 1908, Figs. 28 - 31, 34 - 35; Arora, 1963, p. 118, Fig. 7; Sharma, 1983, p. 35, Fig. 50

Brachionus falcatus f. reducta Koste and Shiel, 1983, p.13 - 114, Fig. 2a, b and 3e

Material: Several parthenogenetic females from Poonthura and Veli-Aakulam estuaries.

Description: Lorica firm, lightly stippled, greatly compressed dorso-ventrally and composed of dorsal and ventral plates; occipital margin with six spines, intermediates much longer than laterals and medians and curved ventrally; medians and laterals are short and almost equal in length; posterior spines widely separated basally, long, their width much more than anterior spines, parallel or bow outwards, converge, then twist towards their apices, thus completing full arch; dorsal plate often

with pustules or granulated; foot opening terminal; mental margin firm and wavy without spine and without elevation towards the centre.

Measurements:

Total length of lorica	222-363 µm
Maximum width of lorica	119-189 µm
Antero-median spine length	17-27 µm
Antero-intermediate spine length	65-121 µm
Antero-lateral spine length	17-29 µm
Postero-median spine length	80-176 µm
Maximum width-total length ratio	0.33-0.56

Distribution in India: Punjab, Rajasthan, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh, West Bengal and Bihar.

Elsewhere: Queensland, Australia, Japan, Africa, Nigeria, Thailand, Malaysia, Singapore and Sri Lanka.

Comments: *B. falcatus* is not such a variable species. Majority of the specimens had posterior spines bowed inwards as an adaptation for floatation. Different morphs are reported from Sri Lanka (Chengalath *et al.*, 1974), Australia (Koste and Shiel, 1983) and India (Arora, 1963, Sharma, 1980a, Sharma *et al.*, 1992). The forms represented in the present collection are given below with their diagnostic features and measurements:

Form 1: *Brachionus falcatus f.* β Apstein, 1907 (Figs. 36-37)

Form 2: *Brachionus falcatus f. lyratus* Lemmerman, 1908 (Fig. 38)

Form 3: *Brachionus falcatus f. hamatus* Lemmerman, 1908 (Fig. 39)

	Diagnosis
Form 1	Posterior spines bowed inwards
Form 2	Posterior spines not incurved; Parallel
Form 3	Posterior spines not incurved; Posterior spine length-body width ratio is >1/2

Measurements (μm)	Form 1	Form 2	Form 3
Lorica length	331	311	275
Lorica width	173	173	129
Antero-lateral spine length	27	26	51
Antero-intermediate spine length	100	104	22
Antero-median spine length	27	26	118
Postero-median spine length	164	156	133

KEY TO THE SPECIES / INFRASPECIES OF *PATULUS* GROUP

01. Lorica with gelatinous cover.....*B. donneri* Brehm, 1951

Lorica without gelatinous cover.....*patulus* group.....2

02. Occipital, postero-lateral and foot opening spines of medium size .....

..... *patulus* (Müller, 1786)

Occipital, postero-lateral and foot opening spines not as above.....3

03. Occipital, postero-lateral and foot opening spines are markedly elongate...

.....*f. macracanthus* Daday, 1905

Occipital and postero-lateral spines of different length; foot opening with three dorsal spine.....*polycanthus* Ehrenberg, 1834

In the present investigation only one species, *B. patulus* was represented from the above-cited species/forms in the key.

Brachionus patulus (Müller, 1786)

(Fig. 40)

Platyias patulus Müller, 1786, p. 361; Voigt, 1957, p. 138, T. 22: 16; Edmondson, 1959, p. 452, Fig. 18: 30b; Arora, 1966; Nayar and Nair, 1969, p. 226, Fig. 7; Nair and Nayar, 1971, P. 45, Fig. 6; Dhanapathi, 1974, p. 367; Kannan and Govindasamy, 1991, p. 41, p. IV, Fig. 3; Sudzuki,

1999, p. 31, pl. 14, Fig. 4, p. 55, pl. 38, Fig. 7.

Noteus patulus Ehrenberg, 1834, p. 145

Brachionus militilaris Ehrenberg, 1837, p.145 - 336; Anderson, 1889, p. 345

Brachionus patulus var. macracanthus Daday, 1905, p. 118 - 119, Fig. 7: 2 - 5

Brachionus patulus Wulfert, 1965, p. 42; Koste, 1978, T. 8, Figs. 1 - 4; Sharma, 1980a, p. 228; 1983, p. 33, Fig. 9; Fernando and Nora, 1981, p. 211, Fig. 4; Koste and Shiel, 1987, p. 973, Fig. 14: 1-7; Bathish, 1992, p. 88, Fig. 74: 1 - 2.

Material: A few parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica firm, sub-rectangular, somewhat compressed dorso-ventrally; anterior margin with ten pronounced spines, four projecting from the dorsal side, four from ventral side and two from lateral; four posterior spines of an unequal size; dorsal medians longest and curved ventrally; lorica rigid dorsally and ventrally with variably formed facets; foot opening in ventral plate, asymmetric in shape and positions.

Measurements:

Total length of lorica	155-164 µm
Maximum width of lorica	116-124 µm
Antero-median spine length	25-36 µm
Antero-intermediate spine length	18-27 µm
Antero-lateral spine length	19-24 µm
Postero-median spine length	23-29 µm
Postero-lateral spine length	17-22 µm
Greatest width- total length ratio	0.71

Distribution in India: Kashmir, Rajasthan, Gujarat, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh and West Bengal.

Elsewhere: Australia, New Zealand, Thailand and America.

Comments: The phenomenon of cyclomorphosis has been observed in *B. patulus*. But in the present collection no such forms have been observed.

KEY TO THE SPECIES / INFRASPECIES OF *URCEOLARIS* GROUP

01. Pectoral margin all triangular; foot opening deep.....
.....*orientalis* Rodewald, 1937

Pectoral margin not as above; foot opening not as above.....2

02. Height/ width (pect. elevation)>1/5.....3

Height/ width (pect. elevation) <1/6.....*rubens* Ehrenberg, 1832

03. Inter-median spines obliterated; lorica elongated.....

.....*novae-zelandiae* Morris, 1913

Inter-median spines not obliterated.....4

04. Lorica posterior extremity extended.....*nilsoni* Ahlstrom, 1940

Lorica posterior extremity without extension.....5

05. Lorica ovoid; the greatest width just below the middle of the lorica.....6

Lorica not as above.....7

06. Occipital intermediate spines present and well developed (not obliterated)

.....*urceolaris* Ehrenberg, 1838

Occipital intermediate spines usually absent if present, obliterated.....

.....*bennini* Leissling, 1924

07. Lorica posterior extremity extended like nilsoni; postero-ventral sinus trifold; antero-intermediate spines present; obliterated.....

.....*pseudonilsoni* Sudzuki, 1992

Posterior extremity not as above; postero-ventral sinus rounded; antero-Inter-mediate present; obliterated .....*kostei* Shiel, 1983

Brachionus kostei Shiel, 1983

(Fig. 41)

Brachionus kostei Shiel, 1983, p. 33 - 34, Figs. 1 - 2; Koste and Shiel, 1987, p. 986, Fig. 19: 7; Segers and Meester, 1994, p. 119, Fig. 13; Sanoamuang *et al.*, 1995, p. 41, Figs. 9 - 10.

Material: One parthenogenetic female from Poonthura estuary

Description: Six pointed occipital spines and two characteristic dorsally convoluted foot-opening spines; lorica stippled; mental margin

elevated and notched medially; the ventral plate with two cuticular ridges with granular borders.

Measurements:

Total length of lorica	133 µm
Maximum width of lorica	89 µm
Anterior lorica width	62 µm
Antero-median spine length	13 µm
Antero-intermediate spine length	3-4 µm
Antero-lateral spine length	13 µm
Posterior spine length	13 µm
Maximum width-total length ratio	0.67
Maximum width- anterior width ratio	0.67

Distribution in India: This is the first report from Kerala and India.

Elsewhere: Australia, Papua New Guinea and Thailand.

Comments: The present record is the fourth for this species. The species is observed from a single locality and also only one. The general morphology of the specimen from Kerala closely resembles that of Thailand (Sanoamuang *et al.* 1995, p. 41, Figs.9 -10) and Australian specimens (Shiel, 1983, p.33 - 34, Figs.1 - 2).

Brachionus rubens Ehrenberg, 1838

(Figs. 42 - 43)

Brachionus urceolaris var. rubens Ehrenberg, 1838, p. 513, pl. 63, Fig. 4

Brachionus rubens Hudson and Gosse, 1886, pl. 27, Fig. 5; Voigt, 1957, p. 150, pl. 19, Figs. a - b; Koste, 1978, T. 9, Fig. 2 - 3; Sharma, 1980a, p. 228, Fig. 12; 1980b, p. 252, Fig. 20; 1983, p. 32, Fig. 7; Koste and Shiel, 1987, p. 985, Fig. 19: 2; Koste and Poltez, 1987, p. 200, Abb. 6; Patil, 1988, p. 92; Kannan and Govindasamy, 1991, p. 40, pl. III, Fig. 3; Sudzuki, 1999, p. 53, pl. 36, Fig. 4-5

Brachionus rubens var. wemeri Daday, 1905, p. 87-130

Material: A few parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica firm, oval, smooth, compressed dorso-ventrally and composed of dorsal and ventral plates; anterior dorsal margin with six spines, medians longest; all the anterior spines have a strengthening rib; anterior ventral (mental) margin markedly elevated toward the centre, notched medially; posterior spines absent; foot opening with a rectangular aperture dorsally and a large rather oval aperture ventrally.

Measurements:

Total length of lorica	144-190 µm
Maximum width of lorica	111-151 µm
Antero-median spine length	22-26 µm
Antero-intermediate spine length	6.5-13 µm
Antero-lateral spine length	11-17 µm
Greatest width - total length ratio	0.70-0.80
Anterior with - greatest width ratio	0.68-0.76

Distribution in India: Punjab, Rajasthan, Kerala, Tamil Nadu, West Bengal, Orissa, Bihar and Assam.

Elsewhere: Australia, Germany, Turkey, Malaysia, Singapore, Hungary, Japan, Thailand, Africa, North America and South America.

Comments: Rare in occurrence in the plankton samples. This species has a close resemblance with *B. urceolaris*. These two species have been differentiated by their size and mental margin rather than the foot opening and spine variations.

Brachionus urceolaris Müller, 1773

(Figs. 44, 46 & 47)

Tubipors urceus Linnaeus, 1758

Brachionus urceolaris Müller, 1773, p.131; Ehrenberg, 1838, p. 512, pl. 63, Fig. 3; Hudson and Gosse, 1886, pl. 27, Fig. 6; Voigt, 1957, p. 149, T. 19, Figs.1: 11, 14, Fig. 4: 16,

20: 7; Arora, 1963, p. 118, Fig. 8; Sharma, 1983, p. 35, Figs. 64 - 66; Kannan and Govindasamy, 1991, p. 40, pl. III, Fig. 3; Shakuntala Pandey and Singh, 1993, p.145, Fig. 8; Sudzuki, 1999, p. 31, pl. 14, Fig. 1.

Brachionus urceolaris pyriformis Barrios and Daday, 1894, p. 235

Brachionus bursarius Barrois and Daday, 1894, p. 235, pl. 7, Fig. 20.

Brachionus urceolaris urceolaris Gillard, 1948, p.159; Koste, 1978, p. 77, T. 9, Figs. 3a - d; Koste, 1979, p. 239, Fig. 4; Koste and Shiel, 1983, p. 117, Fig. 6a; 1987, p. 985, Fig. 19: 1

Brachionus urceolaris urawensis Sudzuki, 1964, p. 98, pl. 4, Figs. 12 - 14

Material: Several parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica smooth, rounded posteriorly, Greatest width - total length ratio-0.80 - 0.86, the greatest width is a little below the middle of lorica; anterior dorsal margin with six pointed spines, medians longer than laterals, laterals longer than intermediates or equal in length; anterior ventral (mental) margin undulate, with a shallow central sinus flanked on either side by a pointed protuberance; foot opening with a rectangular aperture dorsally and a large oval aperture in the ventral plate; all the anterior spines have strengthening ribs.

Measurements:

Total length of lorica	153-209 µm
Maximum width of lorica	118-163 µm
Anterior-median spine length	26-36 µm
Antero-intermediate spine length	9-13 µm
Antero-lateral spine length	12-13 µm
Anterior width - greatest width ratio	0.58-0.66
Maximum width - total length ratio	0.84-0.86

Distribution in India: Maharashtra, Bihar, Kerala, Tamil Nadu, Andhra Pradesh, West Bengal and Assam.

Elsewhere: Cosmopolitan

Comments: Though cosmopolitan, this species has not been commonly reported from India. It has a close resemblance with *B. rubens* in morphology. The morph, which represented in the present collection, is given below with their diagnostic features, figure and measurements.

Brachionus urceolaris f. irregularispina f. nov.

(Fig. 44)

Diagnosis: The occipital spines greatly reduced, irregular in shape; mental margin slightly undulated.

Measurements:

Total length of lorica	158 µm
Maximum width of lorica	138 µm
Antero-median spine length	16 µm
Antero-inter mediate spine length	11 µm
Antero-lateral spine length	16 µm

Brachionus urceolaris nilsoni Ahlstrom, 1940

(Fig. 45)

Brachionus nilsoni Ahlstrom, 1940, p. 77, pl. 18, Fig. 1 - 5

Brachionus urceolaris nilsoni Koste, 1978, T. 19, Fig. 4a - d; 1979, pl. 239 - 240, Fig. 4; Fernando and Nora, 1981, p. 205 - 219; Koste and Shiel, 1987, p. 987, Fig. 19: 6a-b.

Material: Single parthenogenetic female from Poonthura estuary.

Description: Lorica with weak pustules; foot opening spines not diverging, very pointed, ventrally wide foot opening; similar in shape to *B. urceolaris*. Occipital spines have strengthening ribs.

Measurements:

Total length of lorica	182 µm
Maximum width of lorica	122 µm
Antero-lorica width	87 µm
Antero-median spine length	27 µm
Antero-intermediate spine length	18 µm

Antero-lateral spine length	18 µm
Greatest width- total length ratio	0.67
Anterior width- greatest width ratio	0.71

Distribution in India: This is the first report from Kerala and India.

Elsewhere: America and Australia.

Comments: Rare in occurrence. The present specimen is slightly different from Koste's specimen due to its more ovoid structure of lorica.

Brachionus havanaensis trahea Murray, 1913

(Figs. 48 - 53)

Brachionus trahea Murray, 1913, pl. 13, Fig. 48

Brachionus havanaensis var. trahea, Voigt, 1957, p. 130

Brachionus havanaensis trahea de Ridder, 1966

Brachionus forficula keralaiensis Nayar and Nair, 1969, p. 226, Fig. 2; Nair and Nayar, 1971, p. 45, Fig. 2

Material: A few numbers of parthenogenetic females from Poonthura estuary.

Description: Lorica is firm and divided into dorsal and ventral plates; occipital margin with six spines, medians and laterals are almost equal in length or laterals slightly longer than medians; intermediate spines are highly reduced but invariably present in all examined material; the mental margin is rigid, elevated with a wide 'u'-shaped sinus, flanked with two pointed spines; lorica terminates posteriorly in a pair of stout subequal or unequal spines which are widely separated at their bases; foot opening between the bases of the posterior spines; no internal swelling on posterior spines.

Measurements:

Total length of lorica	129-159 µm
Maximum width of lorica	73-91 µm
Antero-median spine length	13-18 µm
Antero-intermediate spine length	2-3 µm
Antero-lateral spine length	18-22 µm

Posterior spine length	34-49 µm

Distribution in India: So far known only from Kerala.

Elsewhere: N. America

Comments: The present species showed a close affinity to *Brachionus forficula var. keralaiensis* (Nayar and Nair, 1969). According to Nayar and Nair (1969) the major difference between the *B. forficula Keralaiensis* and *B. havanaensis trahea* are: a): distribution, and b): the posterior spine variations. *B. havanaensis* was so far known only from North America and it has the posterior spines originating very close to each other. But the variation in the posterior spines is not a distinguishing character since the caudal spines showed variations in length. Similarly, the present taxon differs from *B. forficula* due to the following characteristics:

a) The present specimen had intermediate spine which is absent in *B. forficula*;
b) The present material doesn't have any internal swelling on the posterior spines;
c) The mental margin of the present taxon is elevated towards the centre with a deeply notched sinus ('U'-shaped sinus).

Apart from this, Sharma and Michael (1980) and Sharma (1983) doubted the existence of Nayar and Nair's taxon in their reviews on Indian rotifers since it is reported only from Kerala. However, the existence of this species is now confirmed through the present study. The Nayar and Nair's specimen and the present material showed clear morphological similarities to each other. Therefore, *B. forficula var. keralaiensis* described by Nayar and Nair (1969) is a synonym of *B. havanaensis trahea* than a variety of *B. forficula*. However, the localized distribution of this taxon in India shows that further confirmation is needed on its distribution and occurrence in different parts of India.

The forms represented in the present collection are given below with their diagnostic features and measurements.

Form 1: *Brachionus havanaensis trahea f. ahlstromi* f. nov. (Fig.51)

Form 2: *Brachionus havanaensis trahea f. asymmetrica* f. nov. (Fig. 52)

	Diagnosis	
Form 1 Form 2	Foot opening spines incurved Foot opening spines unequal in length	
Measurements(μm)	Form 1	Form 2
Lorica length	129	151
Lorica width	73	86
Antero-median spine length	13	17
Antero-intermediate spine length	2	2
Antero-lateral spine length	22	22
Postero-median spine length	34	30/38

KEY TO THE SPECIES / INFRASPECIES OF *QUADRIDENTATUS* GROUP

01. Longest occipital spines, median.....2
    Longest occipital spines, lateral.....*mirus* Daday, 1897
02. Spines (length) of foot opening plate/body (width) ratio>1/3.....
    .....*mirabilis* Daday, 1897
    Spines (length) of foot opening plate/body (width) ratio<1/4.....3
03. Dorso-caudal extension pointed in the middle.....*f. sericus* Rousselet, 1907
    Dorso-caudal extension otherwise.....4
04. Occipital median spines divided.....*ambidentatus* de Ridder, 1991
    Occipital median spines not divided.....5
05. Postero-lateral spine (length)/body (width) ratio<1/2.....6
    Postero-lateral spine (length)/body (width) ratio>1/2.....16
06. Postero-lateral spine (length)/body (width) ratio between1/2-1/3.....7
    Postero-lateral spine (length)/body (width) ratio<1/3.....10
07. Spines of foot opening plate may or may not be present.....
    .....*f. polyceros* Schmarda, 1859
    Spines (length) of foot opening plate- body width ratio=1/5.....8
08. Lorica rectangular.....9
    Lorica square.....*f. melheni* Barrois & Daday, 1894

09. Spines of foot opening thick.....*f. rectangularis* Lucks, 1929
Spines of foot opening otherwise.....*f .michaelsoni* Daday, 1908*
10. Postero-lateral spine absent.....11
Postero-lateral spine (length)/body (width) ratio-1/3-1/10.....12
11. Lorica posterior margin truncated.....*f. rhenanus* Lauterborn, 1893
Lorica posterior margin tapering.....*f. schwoebeli* Koste, 1988
12. Spines of foot opening plate stout.....*f. urawensis* Sudzuki, 1964
Spines of foot opening otherwise.....13
13. Lorica rectangular.....*f. enzii* France, 1894*
Lorica otherwise.....14
14. Pectoral margin elevated.....*f. obesus* Barrois and Daday, 1894
Pectoral margin not elevated.....15
15. Lorica granular.....*f. granulatus* Kertesz, 1894*
Lorica otherwise.....*f. fülleborni* Daday, 1908*
16. Spines of foot opening present.....*f. brevispina* Ehrenberg, 1838
Spines of foot opening may or may not be present.....17
17. Postero-lateral spines bent outside.....*f. divergens* Tschugunoff, 1921
Postero-lateral spines otherwise.....*f. curvata* Tschugunoff, 1921

*As given by Sudzuki (1999)

Brachionus quadridentatus Hermann, 1783
(Figs. 54 – 57 & 59)

Brachionus quadridentatus Hermann, 1783, p. 47, T. II, Fig. 11: 9; Ahlstrom, 1940, p.165, pl. XI, Fig. 9, pl. XII, Figs.1 - 9, PL. XIII, Fig. 3; Voigt, 1957, p. 141, T. 21: 2 a - d, 30, 27: 2; Arora, 1963, p.18, Fig. 9; Dhanapathi, 1974, p. 359, pl. I, Fig. 2; Koste, 1978, T. 11, Figs. 4a - k; Sharma, 1980a, p. 228, Fig. 11; 1980b, p. 251, Figs. 17 - 19; 1983, p. 35, Figs. 57 - 62; Koste and Shiel, 1983, p. 45 ; 1987, p. 978, Figs. 16: 1 - 6; Kannan and Govindasamy, 1991, p. 40, pl. III, Fig. 10; Bathish, 1992, p. 80, Fig. 65: 1 - 8; Sharma *et al.*, 1992, p. 444, Figs. 32 - 35; Shakuntala Pandey and Singh, 1993, p.145, Fig. 5; Sudzuki, 1999, p. 31, pl. 14, Figs. 2 - 3, p. 54, pl. 37, Figs. 5 - 6.

Brachionus bakeri Müller, 1786, p. 359, T. XLVII, Fig. 13, T. L, Figs. 22 - 23; Hudson and Gosse, 1886, pl. 27, Fig. 8

Noteus bakeri Ehrenberg, 1830, p. 48

Brachionus brevispina Ehrenberg, 1838, pl. 64, Fig.1.

Brachionus latissimus Schmarda, 1854, p. 18, pl. IV, Fig. 4

Brachionus chilensis Schmarda, 1859, p. 65, pl. XV, Fig.136.

Brachionus ancylognathus Schmarda, 1859, p. 65, pl. XV, Fig. 137.

Brachionus polyceros Schmarda, 1859, p. 65, pl. XV, Fig. 138.

Brachionus pustulatus Schmarda, 1859, p.65, pl. XV, Fig.139.

Brachionus leydigi Cohn, 1862, p.215, pl.22, Figs.1-3.

Brachionus bidentata Anderson, 1889, p.357

Brachionus rhenanus Lauterborn, 1893, p. 254; Voigt, 1957, pl. 21. Fig. 7; Sharma, 1980b, p. 251, Fig.18

Brachionus bursarius Barrois and Daday, 1894, p. 235, pl. 7, Fig. 20

Brachionus capsuliflorus var melheni Barrois and Daday, 1894, p. 233, pl. 7, Fig.18

Brachionus bakeri var. hyphalmyros Tschugunoff, 1921, pl. 1, Fig. 8

Brachionus bakeri var. hyphalmyros f. curvata Tschugunoff, 1921, Pl. I, Fig. 9

Brachionus backeri var. hyphalimyros f. divergens Tschugunoff, 1921, Pl. I, Fig.10

Brachionus leydigi quadratus Sudzuki, 1964, p. 107, pl.8, Fig.10-11.

Brachionus quadridentatus wrawensis Sudzuki, 1964, p. 107, pl. 13, Figs. 1-2

Brachionus quadridentatus f. monospina Saksena and Kulkarni, 1986

Material: Several parthenogenetic females (both ovigerous and non-ovigerous) from Poonthura and Veli-Aakulam estuaries.

Description: Lorica barrel-shaped, swollen at its posterior third, prolonged posteriorly in two stout and parallel lateral spines, their length is usually more than half the length of the body without spines; anterior dorsal margin with six well developed spines, medians longest and bent outwards, laterals slightly divergent; mental margin elevated, wavy with a median notch flanked on either side by a small tooth like papilla; the ventral-posterior portion of the lorica forms a typical tubular sheath surrounding the foot opening; lorica markedly stippled.

Measurements:

Total length of lorica	193-280 µm
Maximum width of lorica	151-196 µm
Antero-median spine length	33-73 µm

Antero-intermediate spine length	8-17 µm
Antero-lateral spine length	21-56 µm
Greatest width - total length ratio	0.70-0.78

Distribution in India: Punjab, Rajasthan, Bihar, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and Meghalaya.

Elsewhere: Australia, Japan, New Zealand, S. America, Sri Lanka, Argentina and Thailand.

Comments: *B. quadridentatus* is a very common, widely cosmopolitan, highly variable species, having an extensive synonymy. In Wiszniewski (1954) catalogue about 80 synonyms including varieties are listed. Several varieties or forms are reported from different parts of the world, but due to the existence of many intermediate forms, these so-called varieties are not sharply separable. The polymorphism in this species was studied by Saksena and Kulkarni (1986). According to their study, most of the *B. quadridentatus* varieties are forms only. A number of forms are also recorded in the present collection. The recorded forms are given below:

Form 1: *B. quadridentatus f. brevispina* Ehrenberg, 1832 (Fig.54)
Form 2: *B. quadridentatus f. aspina* Saksena and Kulkarni, 1986 (Fig. 55)
Form 3: *B. quadridentatus f. divergens* Tschugunoff, 1921 (Fig. 56)
Form 4: *B. quadridentatus f. melheni* Barrois and Daday, 1894 (Fig. 57)
Form 5: *B. quadridentatus f. curvata* Tschugunoff, 1921 (Fig. 59)

Measurements (µm)	Form 1	Form 2	Form 3	Form 4	Form 5
Lorica length	194	155	415	227	220
Lorica width	157	151	208	121	196
Antero-median spine length	34	43	86	53	76
Antero-intermediate spine length	9	13	11	11	18
Antero-lateral spine length	13	22	26	20	27
Postero-lateral spine length	22	56	159	100	104
Postero-median spine length	-	-	-	-	-
Maximum width-total length ratio	0.78	0.97	0.50	0.53	0.89

	Diagnosis
Form 1	Small in size, small postero-lateral spines; lorica barrel-shaped
Form 2	Single postero-lateral spine; lorica small
Form 3	Postero-lateral spines long and diverged
Form 4	Long occipital median spines; long postero-lateral spines; lorica roughly square
Form 5	Postero-lateral spines long and curved

Brachionus quadridentatus mirabilis Daday, 1897

(Fig.58)

Brachionus mirabilis Daday, 1897, p.140, Fig. 8; Harring, 1913, p.22; Ahlstrom, 1940, p.167, pl. XI, Figs.5 - 8; Sharma, 1983, p. 35, Fig. 63; Sharma *et al.*, 1992, p. 438, Fig. 8.

Brachionus quadridentatus mirabilis Koste, 1978, p. 75.T. 11: 5 a - d; Koste and Shiel, 1987, p. 980, Figs.12, 16: 3; Shakuntala Pandey and Singh, 1993, p. 145, Fig. 6.

Material: One parthenogenetic female from Poonthura estuary.

Description: Lorica barrel-shaped, anterior dorsal margin with six well developed spines, medians longest and bent outwards, laterals slightly divergent; antero-median, postero-median, postero-lateral spines extremely long.

Measurements:

Total length of lorica	247 µm
Maximum width of lorica	136 µm
Antero-median spine length	38 µm
Antero-intermediate spine length	18 µm
Antero-lateral spine length	27 µm
Postero-median spine length	89 µm
Postero-lateral spine length	129 µm
Greatest width - total length ratio	0.56

Distribution in India: Bihar, Kerala, West Bengal and Assam.

Elsewhere: Pan tropical, Australia, Africa, South and Central America, New Guinea, Thailand, Malaysia and Singapore.

Comments: It is the first report from Kerala. Koste (1978) considered it as a subspecies of *B. quadridentatus,* but according to Sharma (1979, 1983) and Sharma *et al.* (1992) it is a separate species. However, this taxon has close resemblance with *B. quadridentatus* as the mental margins of both are similar. Because of the close similarities between these two species, Koste's opinion seems to be more applicable for this taxon than that of Sharma. One of the interesting observations on this species is its occurrence. The occurrence is very rare. Only one specimen was represented in the present collection.

KEY TO THE SPECIES / INFRASPECIES OF *PLICATILIS* GROUP

01. Lorica triangular.....2
    Lorica not as above.....4
02. Occipital spines finger-like; pectoral margin with all triangular projections... ..... *bayleyi* Sudzuki & Timms, 1977
    Occipital spines and pectoral margin are not as above.....3
03. Posterior spines present; two numbers and stout..... .....*satanicus* Rousselet, 1913
    Posterior spines absent.....*spatiosus* Rousselet, 1907
04. Lorica elliptical; occipital spines saw-teethed; broad based; pectoral margin four lobed.....*plicatilis* Muller, 1786
    Lorica, occipital spines and pectoral margin are not as above.....5
05. Lorica vase-shaped; occipital spines small based; elevated lateral pectoral projections.....*rotundiformis* Tschugunoff, 1921
    Lorica not as above; inter-medians comparatively short; pectoral margin four lobed showed considerable variations (some times obliterated or wavy or scalloped or straight line)..... .....*murray* Murray, 1913

Brachionus plicatilis Müller, 1786

(Figs. 60 - 73)

Brachionus plicatilis Müller, 1786, p. 344, pl. L, Figs.1-8; Hauer, 1925, p.30, Fig. 3. b; 1957; Ahlstrom, 1940, p. 149, pl. II, 1, 2' 6, 9; Wulfert, 1943, p. 165, Fig.1; Varga, 1951, p. 221-222, Fig. 15; Wiszniewsky, 1954, p. 23 - 24; Voigt, 1957, p. 150, T. 22: 1, 27: 4; Sudzuki, 1964, p. 102, pl. 8, Figs. 12 - 13; Sharma, 1980, p. 251, Fig. 16; 1983, p. 23, Fig. 4; Yúfera, 1982, p. 56, Fig. 1; Koste and Shiel, 1987, p. 983, Fig.18: 3b, 4a, b, d, f, 5; Kannan and Govindasamy, 1991, p. 39, pl. II, Fig. 9; Bathish, 1992, p. 89, Fig. 75: 1-2; Shakuntala Pandey and Singh, 1993, p.145, Fig. 3; Serra *et al.*, 1998, p. 376, Fig. 3.

Brachionus mülleri Ehrenberg, 1834, p. 200; 1838, pl. LXIII, Fig. V

Brachionus hepatotomus Gosse, 1851, p. 203; Hudson and Gosse, 1886; Hada, 1937, p. 579 - 589, Figs.1- 3

Brachionus plicatilis var. spatiosus Fadeew, 1925A, p. 22.

Brachionus plicatilis f. decemcornis Fadeew, 1925A, p. 22, pl. IV, Fig. 7

Brachionus plicatilis f. mülleri Tschugunoff, 1921, pl. 1, Fig. II; Hauer, 1925, Fig. 3a

Brachionus plicatilis f. hepatotomus Harring, 1913, p.22; Sudzuki, 1999, p. 29, pl. 12, Figs.4-5

Brachionus plicatilis plicatilis Koste, 1978, T. 9, Figs.1a; 1979, p. 240, Fig. 7; Koste and Shiel, 1987, p. 983, Fig.18: 3b, 4a

Material: Several parthenogenetic females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica rather flexible, oval, not sharply separated into dorsal and ventral plates, but little compressed dorso-ventrally; anterior dorsal margin with six broad-based saw-tooth spines, nearly equal in length; mental margin rigid, separated into four lobes with considerable variations; lorica without posterior spines; smooth or lightly stippled; foot opening with small subsquare aperture ventrally.

Measurements:

Total lorica length	171-277 µm
Maximum width of lorica	156-225 µm
Anterior lorica width	103-156 µm
Distance from lateral to median spine	33.4-68.8 µm
Median sinus gape	12-22 µm

Antero-median spine length	20-43 µm
Antero-intermediate spine length	9-34 µm
Antero-lateral spine length	15-30 µm
Maximum width - total length ratio	0.81-0.91
Anterior width - maximum width ratio	0.67-0.69
Anterior width - total length ratio	0.56-0.60
Egg size	98 x 87µm

Distribution in India: Punjab, Bihar, Kerala, Tamil Nadu and Andhra Pradesh.

Elsewhere: Cosmopolitan widely distributed in brackish water and salt waters. Australia, Devils Lake, North Carolina, Florida, California, Britain, Columbia, Haiti, Brazil, Argentina, Sweden, France, Kenya, Africa, Thailand, Nepal, Malaysia, Sri Lanka, Germany, New Zealand, Spain, China and Japan.

Comments: Among rotifers, *B. plicatilis* is probably one of the best-studied taxa because of its aquaculture potential as live feed for various fish and shellfish larviculture. It has been widely used as a model for physiological and ecological studies. However, in the last decade, several comparative studies (Fu *et al.*, 1991a, 1991b, 1993; Rumengan *et al.*, 1991; Rico-Martínez and Snell, 1995a, b) revealed that *B. plicatilis* is not a single species but a complex of at least two morphologically recognized taxa, the so-called 'L' (Large) and 'S' (Small) type. On the basis of this evidence, Segers (1995) re-examined this existing available names and proposed that *B. plicatilis* Muller, 1786 and *B. rotundiformis* Tschugunoff, 1921 was the correct names for the 'L' and 'S' type, respectively. Since then, those names have been applied to several strains from all over the world. However, several recent studies on molecular markers and ecological genetic studies on *B. plicatilis* from Spain (Gomez and Serra, 1995; Serra *et al.*, 1997, 1998) revealed that *plicatilis* species complex are in fact composed of a cluster of sibling species, and they reported the co-occurrence of three biological species instead of two. They reported these rotifers under the names of *B. plicatilis* (the original Muller's *plicatilis*), B.

rotundiformis 'SS' type (the original Tschugunoff, *rotundiformis*) and *B. rotundiformis* 'SM' type from Spanish waters. However, Serra *et al.* (1998) expressed a doubt about the correct taxonomic status of *B. rotundiformis* 'SM' type in the Spanish waters since most of the genetic characters are comparable to both *B. rotundiformis* 'SS' and 'SM'. They also reported morphological and reproductive variations between these rotifers. Because of their close genetic similarities they grouped into one category. Recently, Ciros-Pérez *et al.* (2001) based on the morphology, morphometric analysis, reproductive patterns and other genetic studies, the rotifer *B. rotundiformis* 'SM' was taxonomically segregated from Tschugunoff's *rotundiformis* and they named it as a new species *B. ibericus*. n. sp.

Similarly, in the present study three morphologically distinct species were observed under the *plicatilis* complex. Based on the morphological characters (occipital spines and mental margin) from the original description and other related reports (Koste, 1978; Sudzuki, 1995, 1996, 1999) of *B. plicatilis* by Müller (1786) correspond well with the 'L' type.

A number of morphs were observed in the plankton samples as well as in the clones maintained in the laboratory at different salinity, temperature and feed type. The most frequently observed morphs are given below with their important diagnostic features and measurements:

Form 1: *B. plicatilis f. mülleri* Ehrenberg, 1838 (Fig. 62)
Form 2: *B. plicatilis f. hepatotomus* Gosse, 1851 (Fig.64)
Form 3: *B. plicatilis f. decemcornis* Fadeew, 1925 (Fig. 67-73)
Form 4: *B. plicatilis f. ovalis* f. nov. (Fig.69-72)

	Diagnosis
Form 1	Occipital spines broad-based; metal margin obliterated; nearly straight
Form 2	Occipital spines with external swellings; pectoral margin not obliterated
Form 3	Occipital spines without external swellings; median elevated pectoral margin
Form 4	Lorica ovoid to roughly spherical in shape; occipital spines scalar in arrangement

Measurements (μm)	Form 1	Form 2	Form 3	Form 4
Lorica length	242	192	288	278
Lorica width	190	167	216	200
Anterior lorica width	164	115	133	103
Antero-median spine length	26	22	29	23
Antero-intermediate spine length	17	11	22	16
Antero-lateral spine length	26	12	16	11
Median sinus gape length	14	9	11	12
Maximum width-total length ratio	0.79	0.86	0.78	0.71
Anterior width-maximum width ratio	0.86	0.69	0.62	0.52

Brachionus murray Murray, 1913

(Figs. 74 – 90)

Brachionus mülleri var. murray Murray, 1913, p. 499-451, Figs. 47a - c

Brachionus plicatilis var. ecornis Fadeew, 1925, p. 22, pl. IV, Fig. 4 - 5

Brachionus plicatilis ecornis Wiszniewsky, 1954, p. 24

Brachionus plicatilis from OVII Hauer, 1925, Fig. 3b

Brachionus plicatilis 'S' type Yúfera, 1982, p. 56, Fig. 1; Fu *et al.*, 1991, p. 30, Fig.1a

Brachionus rotundiformis Sudzuki, 1987, p. 46, Figs.1: 8-10; 1999, p. 52, pl. 35, Fig. 5

Material: Several parthenogenetic (both ovigerous and non ovigerous) females from Veli-Aakulam and Poonthura estuaries.

Description: Lorica small ovoid to elliptical and not sharply separated into dorsal and ventral plates; occipital spines six in number which are narrow markedly above the broad, inflated base and end in thin, acutely pointed tips or small based equilateral, equidistant triangular spines; the mental margin rigid and scalloped, shows considerable variations, irregularity of the four rounded projections; the occipital spines also show considerable variations especially in the relative length of intermediate spines ; posterior spines absent; foot opening with a small subsquare aperture ventrally.

Measurements:

Total length of lorica	150-213 µm
Maximum width of lorica	116-144 µm
Antero-median spine length	22-36 µm
Antero-intermediate spine length	11-18 µm
Antero-lateral spine length	13-22 µm
Greatest width - total length ratio	0.67-0.77
Anterior width - greatest width ratio	0.63-0.68

Distribution in India: Kerala. This is the second report of this species from India. Gopakumar (1998) has reported this species under the name *B. plicatilis* 'S' type (Kadinamkulam strain) from Kerala. It is interesting to note that the distribution of this taxon in India is restricted to brackish water habitats of Kerala only. Because of the restricted distribution, further study is needed on the distribution and occurrence of this taxon in different brackish water habitats of India.

Elsewhere: Japan, America, Thailand, Australia, Spain, Russia, Kenya and Kuwait.

Comments: *B. murray* was originally established as a new variety of *B. mülleri* var. *murray* based on the specimens from Murray River (Murray, 1913). A number of workers such as Fadeew (1925), Hauer (1925), Ahlstrom (1940) and Wiszniewsky (1954) reported this taxon as variety of *B. plicatilis* (*f. longicornis*). Recently Segers (1995) reviewed the present status of this taxon and found that it was inadequately described and hence, placed it under 'species inquirendae' However, in the present study this taxon closely match (morphological characteristics) the known species *B. mülleri var. murray*. Although, there are similarities (morphological) between *B. ibericus* (Ciros-Perez *et al.*, 2001) and the present taxon, distinct differences in the mental margin of the forms and the relative length of the occipital spines especially the inter-medians (comparatively shorter in all the measured specimens) in different salinity and temperature conditions; whereas the occipital spines of *B. ibericus* was

uniform in length (Ciros-Perez *et al.*, 2001) at one temperature (23°C) and salinity (12 ppt). However, these authors did not mention the morphological variations especially in occipital spines and mental margin variations at varying temperature and salinity. Therefore, the present taxon occurred in the backwaters of Kerala is named as *B. murray* based on the morphological characteristics (mental margin and occipital spines) mentioned in the key (Sudzuki, 1999). This would facilitate the future recognition of this taxon.

The morphs represented in the present collection are given below with their measurements and important diagnosis:

Form 1: *B. murray f. ecornis* Fadeew, 1925 (Figs. 81-83 & 89)

Form 2: B. murray *f. longicornis* Fadeew, 1925 (Figs. 82-83)

Form 2: *B. murray f. divergispinus* f. nov. (Figs. 87-88)

	Diagnosis
Form 1 Form 2 Form 3	Pectoral margin wavy or obliterated or nearly straight Occipital spines equilateral; equidistant; scalloped pectoral margin Occipital spines diverged especially on the lateral ones; mental margin four lobed

Measurements (μm)	Form 1	Form 2	Form 3
Lorica length	193	213	156
Lorica width	178	144	129
Antero-median spine length	27	26	22
Antero-intermediate spine length	13	24	9
Antero-lateral spine length	26	24	12
Maximum width-total length ratio	0.92	0.67	0.83

Brachionus rotundiformis Tschugunoff, 1921
(Figs. 91- 99)

Brachionus mülleri Ehrb. *var. rotundiformis* Tschugunoff, 1921, p. 120, pl. 1, Fig. 12

Brachionus plicatilis var. rotundiformis Fadeew, 1925, p. 22, Fig. 6

Brachionus plicatilis rotundiformis Rodewald, 1937, p. 239, Fig. 5; Wisniewski, 1934, p. 54

Brachionus plicatilis Bs. Yúfera, 1982, p.56, Fig.1a

Brachionus rotundiformis estoniana Sudzuki, 1987, p. 46, Fig. 2; Haberman and Sudzuki, 1998, p. 335, Fig. 2

Material: Five parthenogenetic females from Veli-Aakulam estuary.

Description: Lorica small more rounded and not sharply separated into dorsal and ventral plates; occipital margin with small based acutely pointed spines; mental margin four-lobed, lateral ones roughly triangular; foot opening with subsquare aperture ventrally and rather ovoid aperture dorsally.

Measurements:

Total length of lorica	98-156 µm
Maximum width of lorica	87-125 µm
Antero-width of lorica	51-73 µm
Antero-median spine length	11-22 µm
Antero-intermediate spine length	9-13 µm
Antero-lateral spine length	9-13 µm
Maximum width- total length ratio	0.80-0.89
Anterior width-maximum width ratio	0.58-0.59
Anterior width- total length ratio	0.52-0.47

Distribution in India: Kerala. It was recorded earlier from Dalavapuram (Kerala) as *B. plicatilis* 'S' type, Dalavapuram strain by Gopakumar (1998).

Elsewhere: Caspian Sea, Japan, Kuwait, Florida, Russia and Spain.

Comments: *B. rotundiformis* was originally established as *B. mülleri var. rotundiformis* (Tschugunoff, 1921) from Caspian Sea. Afterwards, a number of workers reported this taxon under the name *B. plicatilis f. rotundiformis* (Fadeew, 1925; Ahlstrom, 1940; Hauer, 1925). However, aquaculturists called it as *B. rotundiformis* 'ss' type because of its smaller size than the other rotifers such as *B. plicatilis* and *B. rotundiformis* 'S'

type. In 1995, Segers reclassified this taxon and he confirmed that the *B. rotundiformis* 'ss' type is the original Tschugunoff's *rotundiformis.* It is interesting to note that in the present study unlike the *B. plicatilis* and *B. murray* the mental margin of this taxon was very distinct (with elevated lateral mental margin) in all the specimens in the plankton samples as well as in the cultured clones maintained in the laboratory.

The morph represented in the present collection is given below with its important diagnostic features and measurements.

Brachionus rotundiformis f. semicircularis f. nov. (Fig.97)

(Figs. 97 - 99)

Diagnosis: Lorica vase shaped; posterior half of the lorica swollen.

Measurements:

Total length of lorica	150-155 µm
Maximum width of lorica	129-133 µm
Antero-width of lorica	73-103 µm
Antero-median spine length	22 µm
Antero-intermediate spine	13 µm
Antero-lateral spine length	13 µm
Egg size	90 µm x 65 µm

Genus: **Keratella** Bory de St. Vincent, 1822

Robust rectangular, trapezoid or ovoid lorica, dorsally vaulted, ventrally flat; anterior lorica margin with five ventrally directed spines (except Keratella reducta); posterior lorica rounded, tapering, terminating with a single median caudal spine, paired postero-lateral spines or a single postero-lateral spine; caudal spines may be absent; dorsal lorica with or without a keel, generally with polygonal panels (plaques) arranged in symmetric or asymmetric facets; medians, lateral, frontal and carinal plaques are essential taxonomic characters; dorsal lorica is variously structured; smooth, pitted, granular or

covered with fine spinules; ventral plate may have similar structures only on the upper part ; foot absent; corona a three-lobed circumspectly band; large mastax with malleate trophi.

Type: *Keratella quadrata* Bory de St. Vincent, 1822.

This genus is divided into several species based upon the following characters (Ahlstrom, 1943; Gillard, 1948):

i). the presence or absence of posterior spines, their numbers and position.
ii). the pattern of dorsal sculpture on the lorica.
iii). the proportions of the body especially as regards size, shape, width and depth.
iv). the number of anterior spines.
v). the ornamentation of the ventral plate.
vi). the ornamentation of the dorsal plate.

The genus contains to date, approximately 16 known species, which are placed in recognized, defined, morphological groups principally on the basis of the variable lorica form. The genus can be divided into three groups. They are *quadrata, valga-tropica* and *cochlearis* depending on their variable lorica. However, in the present collection only two species were recorded.

KEY TO SPECIES GROUP OF THE GENUS *KERATELLA*

01. Anterior spines four in number; posterior spines absent.....
.....*Parakeratella*
Anterior spines six in number; posterior spines present or absent.....
.....*Keratella*.....2
02. Lorica almost square; posterior spines equal in length.....*quadrata* group
Lorica tapering; posterior spines present.....3
03. Lorica tapering; single posterior spine.....*cochlearis* group

Lorica tapering; two posterior spines; asymmetrical.....*valga/tropica* group

KEY TO THE SPECIES / INFRASPECIES OF *COCHELARIS* GROUP

01. Occipital spines curved.....*f. recurvispina* Jägerskiöld, 1898*
    Occipital spines not as above.....2
02. Lorica densely covered by spinlets.....*f. hispida* Lauterborn, 1898
    Lorica otherwise.....3
03. Lorica with posterior spines.....4
    Lorica without posterior spines.....*f. tecta* Lauterborn, 1894

Keratella cochelaris (Gosse, 1851)

(Figs. 100 -102)

Anuraea cochelaris Gosse, 1851, p. 202; Hudson and Gosse, 1886, pl. 29, Fig. 7; Lauterborn, 1900, p. 412-448; Voigt, 1957, pl. 23, Fig. 12

Anuraea cochlearis recurvispina Jägerskiöld, 1894, p.19, Fig.12

Anuraea cochlearis macracantha Lauterborn, 1898, p. 598-601, Fig.1

Anuraea cochlearis tecta Lauterborn, 1898, p. 598-601, Fig. 3

Anuraea cochlearis hispida Lauterborn, 1898, p. 598-601, Fig. 4

Anuraea cochlearis irregularis Lauterborn, 1898, p. 598-601, Fig. 5

Keratella cochlearis Harring, 1913; Klement, 1955, p. 321, Figs.1a-c; Voigt, 1957, p. 177, T. 23, 12, Abb. 17: Au, B; Sudzuki, 1957, Fig. 13; 1962, p. 51, Fig.14; 1964, p. 109, pl. 15, Figs.1-16; 1999, p. 33, pl.16, Figs. 2-4, p. 57, pl. 40, Figs. 4-7; Dhanapathi, 1974, p. 363, pl. III, Fig. 6; Daems and Dumont, 1974, p. 70, Fig.12a-b; Koste, 1978, p.110-115, T. 22, Fig. 4, T. 23, Figs. 7-12, T. 24, Figs.1-7, T. 25, Figs.1-14; 1979, p. 245, Fig.17a-d; Koste and Poltz, 1987, p. 208-209, Abb.11a-c, Abb.12; Koste and Shiel, 1987, p.1008, Fig. 31:1a-c; Sharma, 1987, p. 272, Figs.18-19; Kannan and Govindasamy, 1991, p. 40, pl. III, Fig. 8

Material: Several parthenogenetic females from Poonthura estuary.

Description: Lorica with a stout median posterior spine which usually varies in length or completely wanting; anterior dorsal margin with six spines; medians longest, curved ventrally; intermediates usually slightly divergent, somewhat shorter than lateral spine, which are convergent at their tips

which arise at a single angle toward the ventral; foundation pattern of the dorsal plate characterized by a median line behind the median frontal area to the base of the posterior spine; only one pair of fully enclosed carinal plates often present, or the dorsal pattern is absent and the postulation very faint.

Measurements:

Total length of lorica	111-151 µm
Maximum width of lorica	47-86 µm
Antero-median spine length	24-51 µm
Intermediate spine length	7-20 µm
Lateral spine length	9-13 µm
Posterior spine length	13-36 µm

Distribution in India: Kashmir, Kerala and Andhra Pradesh.

Elsewhere: Nepal, Australia, Spain, Germany, South America Singapore Thailand and Africa.

Comments: This is also a variable species, the variability mainly on size of the spines and dorsal lorica pattern. The morphs represented in the present collection are given below with their diagnostic features, measurements and figures.

Keratella cochlearis f. tecta Lauterborn, 1894

(Fig. 101)

Diagnosis: Lorica without posterior spines or obliterated

Measurements:

Total length of lorica	111 µm
Maximum width of lorica	86 µm
Antero-median spine length	27 µm
Intermediate spine length	7 µm
Lateral spine length	13 µm
Posterior spine length	13 µm

Keratella cochlearis f. recurvispina Jägerskiöld, 1894*

(Fig. 102)

Diagnosis: Occipital spines long, incurved especially the intermediate spines.

Measurements:

Total length of lorica	151 µm
Maximum width of lorica	47 µm
Antero-median spine length	51 µm
Intermediate spine length	20 µm
Lateral spine length	11 µm
Posterior spine length	33 µm

* As given by Sudzuki, 1999

KEY TO THE SPECIES / INFRASPECIES OF *TROPICA* GROUP

01. Postero-median facets hexagonal; post-median remnant present.....
.....*tropica*.....2

Postero-median facets hexagonal; post-median remnant absent.....
.....*valga* Ehrenberg, 1834

02. Posterior spines two in number; posterior spine-body (without spines) ratio <1.....*f. asymmetrica* Barrois and Daday, 1894

Posterior spines one in number.....*f. aspina* Fadeew, 1925

Keratella tropica (Apstein, 1907)

(Figs. 103 -105)

Anuraea valga f. tropica Apstein, 1907, p.210, Fig. F: (a)

Anuraea aculeata var. tropica Tschugunoff, 1921, Figs.13-14

Keratella valga f. tropica Edmondson and Hutchinson, 1934, Fig.4c-e; Hauer, 1937, Fig.30a; Sudzuki, 1964, pl.17, Figs.18-19

Keratella tropica Ahlstrom, 1943, p. 451, pl. 42, Figs. 1-20; Berzins, 1955, p. 554, Figs. 2 - 3; Dhanapathi, 1974, p. 363, pl. III, Figs. 4 - 5; Daems and Dumont, 1974, p. 70, Fig.13; Koste, 1978, p. 17, T. 17, Figs. 2 (a-b), 11, 12 (a-b) and T. 20, Fig.1 (a - g); 1979, p. 249, Fig. 15; Sharma, 1979b, p. 345 - 347, pl. III, Fig. 10; 1980a, p. 228, Figs.14-15; 1980b, p. 252, Fig. 24; 1987, p. 272, Figs. 9 - 15; Koste and Shiel, 1987, p. 1001,

Figs. 26: 2, 27: 1; Kannan and Govindasamy, 1991, pl. IV, Fig.1; Sharma *et al.*, 1992, p.444 - 445, Figs. 36 - 38; Bathish, 1992, p. 91, Figs. 77: 1 - 4; Sudzuki,1999, p. 56, pl. 39, Figs. 1 - 3.

Material: Several parthenogenetic females from Poonthura estuary.

Description: Lorica compressed dorso-ventrally; the anterior dorsal margin with six spines, medians being the longest, stoutest and curved ventral wards; laterals usually little longer than intermediates; lorica with two unequal posterior spines; right spine being always longer than the left; the dorsal surface of lorica consists of the median polygons and a small four-sided structure and three pairs of marginal.

Measurements:

Total length of lorica	198-249 µm
Maximum width of lorica	62-89 µm
Antero-median spine length	18-44 µm
Intermediate spine length	11-33 µm
Lateral spine length	13-24 µm
Right postero-lateral spine length	47-98 µm
Left posterior spine length	9-22 µm

Distribution in India: Kashmir, Punjab, Rajasthan, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal, Meghalya and Manipur.

Elsewhere: Australia, Indonesia, Africa, Malaysia, Singapore, Thailand, Japan, Nigeria and Nepal.

Comments: This species show morphological variations, mainly on the relative length and presence of the postero-lateral spines. According to Pejler (1962, 1980), some environmental factors such as temperature, food availability and intraspecific biotic relationships cause form variations in rotifers.

The different forms represented in the present collection are given below with their figures diagnostic characters and measurements.

Keratella tropica f. asymmetrica Barrois and Daday, 1894

(Fig. 103)

Diagnosis: Posterior spines unequal in length.

Measurements:

Total length of lorica	222 µm
Maximum width of lorica	81 µm
Antero-median spine length	44 µm
Intermediate spine length	33 µm
Lateral spine length	24 µm
Left postero-lateral spine length	9 µm
Right postero lateral spine length	67 µm

Keratella tropica f. aspina Fadeew, 1925

(Fig. 105)

Diagnosis: Single posterior spine.

Measurements:

Total length of lorica	200 µm
Maximum width of lorica	62 µm
Antero-median spine length	29 µm
Intermediate spine length	13 µm
Lateral spine length	22 µm
Postero-lateral spine length	76 µm

DISCUSSION

The rotiferan taxonomy was expanded explosively for the past three hundred years and even more intensified research is going on in different parts of the world and new species are still being described from well-studied region such as Europe, Australia and Northeast U. S. A. Currently 1817

species of rotifers are known to be described from different parts of the world (Segers, 2002). However, 310 species of rotifers belonging to 60 genera are so far known from Indian waters (Sharma, 1991). During the present investigation, 44 species of rotifers belonging to 15 genera have been recorded from Southern Kerala. Eighteen species of rotifers have been documented by Nayar and Nair (1969) from Irinjalakuda, Trichur (Northern Kerala). According to Sharma (1991), only 24 species of rotifers were reported from Kerala, while Harikrishnan (1993) and Anuradha Rammohan (1996) have documented 24 and 25 species of rotifers respectively from Southern Kerala, especially from Trivandrum and Kollam. Gopakumar (1998) reported 30 species of rotifers from different estuaries of Kerala. However, the total numbers of species recorded from Kerala is less when compared to the total number of species recorded from other parts of India.

Out of the 44 species of rotifers recorded during this study, 22 belong to the family Brachionidae, five to Lecanidae, four to Filiniidae, and two to Mytilinidae; one species each to Epiphanidae, Trichotriidae, Notommatidae, Synchaetidae and Asplanchnidae. The most diverse genus was *Brachionus* which represented 14 species in the present study. The abundance of *Brachionus* species in tropical rotifer fauna has been pointed out by Green (1972), Pejler (1977b), Sharma and Michael (1980) and Gopakumar (1998). Thus, the abundance of *Brachionus* species in the present study is in accordance with the findings of workers cited above. It is also significant to note that the following rotifers are for the first time recorded from India: *B. dichotomus reductus*, *B. urceolaris nilsoni* and *B. kostei*; the following rotifers are reported for the first time from Kerala: *B. calyciflorus borgerti* and *B. quadridentatus mirabilis*. Among these, *B. dichotomus reductus* and *B. kostei* are previously considered as endemic to Australia (Koste and Shiel, 1987) were also found in the present collection. The other reports of this species from outside Australia are only from Thailand (Sanoamuang *et al.*, 1995; Sanoamuang, 1998). On the other hand, the species such as *B. donneri*, *B. durgae* and *Keratella edmonsini* are believed to be endemic to India, but in

the present study these species are not represented in the plankton collection. However, *B. donneri* has been reported by Harikrishnan (1993) from Neyyar Dam. But, Sanoamuang *et al.* (1995) have reported these rotifers from Thailand, indicating that these are no more endemic to India. The present study shows the similarity of rotifer fauna of Kerala, Australia (tropical area) and Thailand because most of the species belonging to the genus *Brachionus* represented in these areas. *Brachionus havanaensis trahea* was earlier reported under the name *B. forficula keralaiensis*, a variety of *B. forficula* by Nayar and Nair (1969) and Nair and Nayar (1971) from Kerala waters but the present study reveal that *B. forficula keralaiensis* is not a variety of *forficula*; it is a synonymy of *B. havanaensis trahea*. However, recent reviews on Indian rotifers (Sharma and Michael, 1980; Sharma, 1983) doubted the report of this variety, which is now confirmed as a separate taxon.

In this investigation it was revealed that *B. plicatilis* is not a single species but a complex of at least three morphologically recognized taxa, *B. plicatilis* (so-called 'L' type), *B. murray* (*B. rotundiformis* 'SM' or 'S') and *B. rotundiformis* (*B. rotundiformis* 'ss' by aquaculturists). Thus, the present study clearly illustrates that the rotifer records of Kerala requires an updating. The occurrence of new species in the present study has revealed that further study will increase the number of species and also provide more information about Kerala rotifer biogeography.

FIGURE 1: MAP OF POONTHURA ESTUARY SHOWING THE COLLECTION SITES

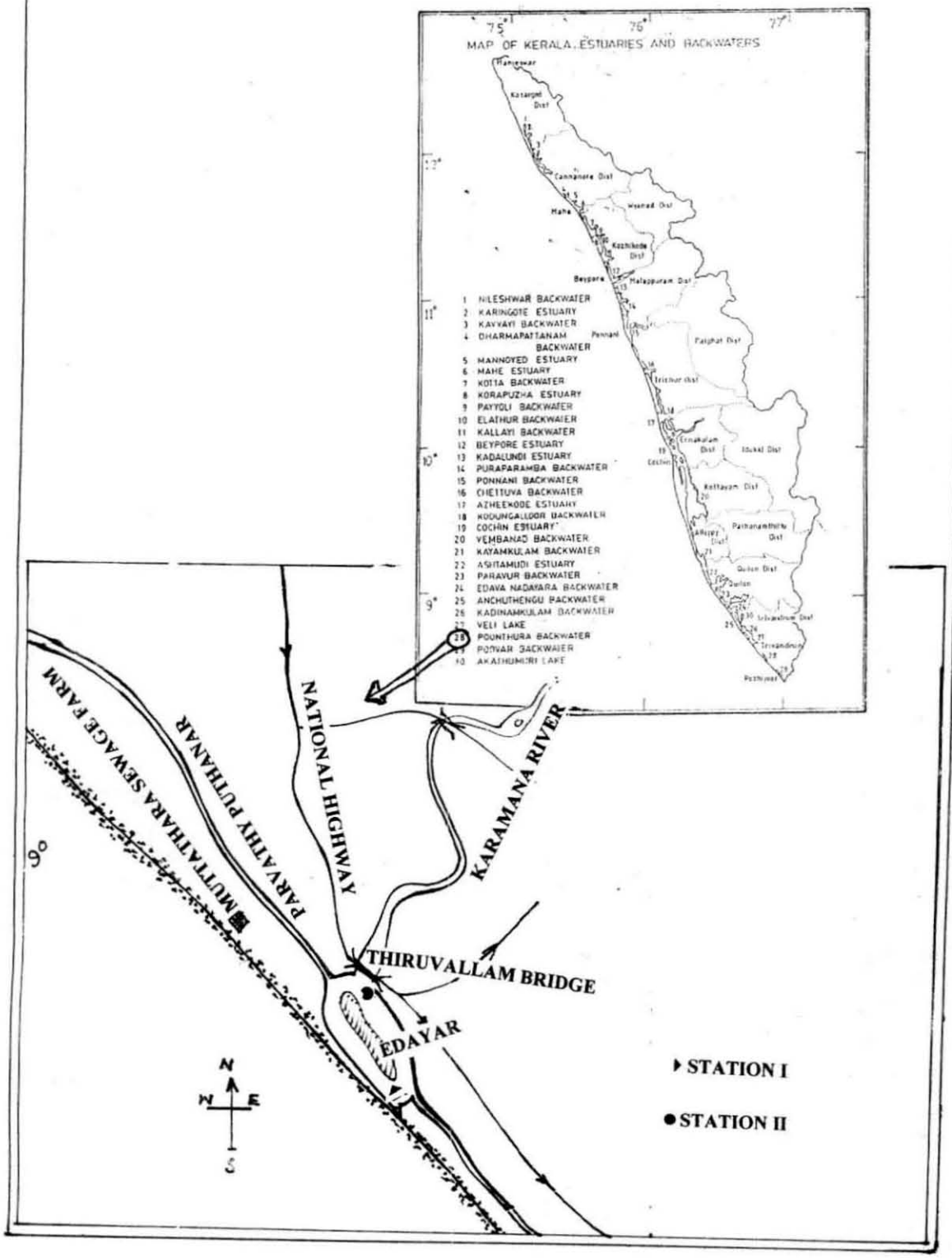


PLATE 1

A view of Poonthura estuary at Station 1

A view of Poonthura estuary at Station 2

FIGURE 2: MAP OF VELI-AAKULAM ESTUARY SHOWING THE COLLECTION SITES

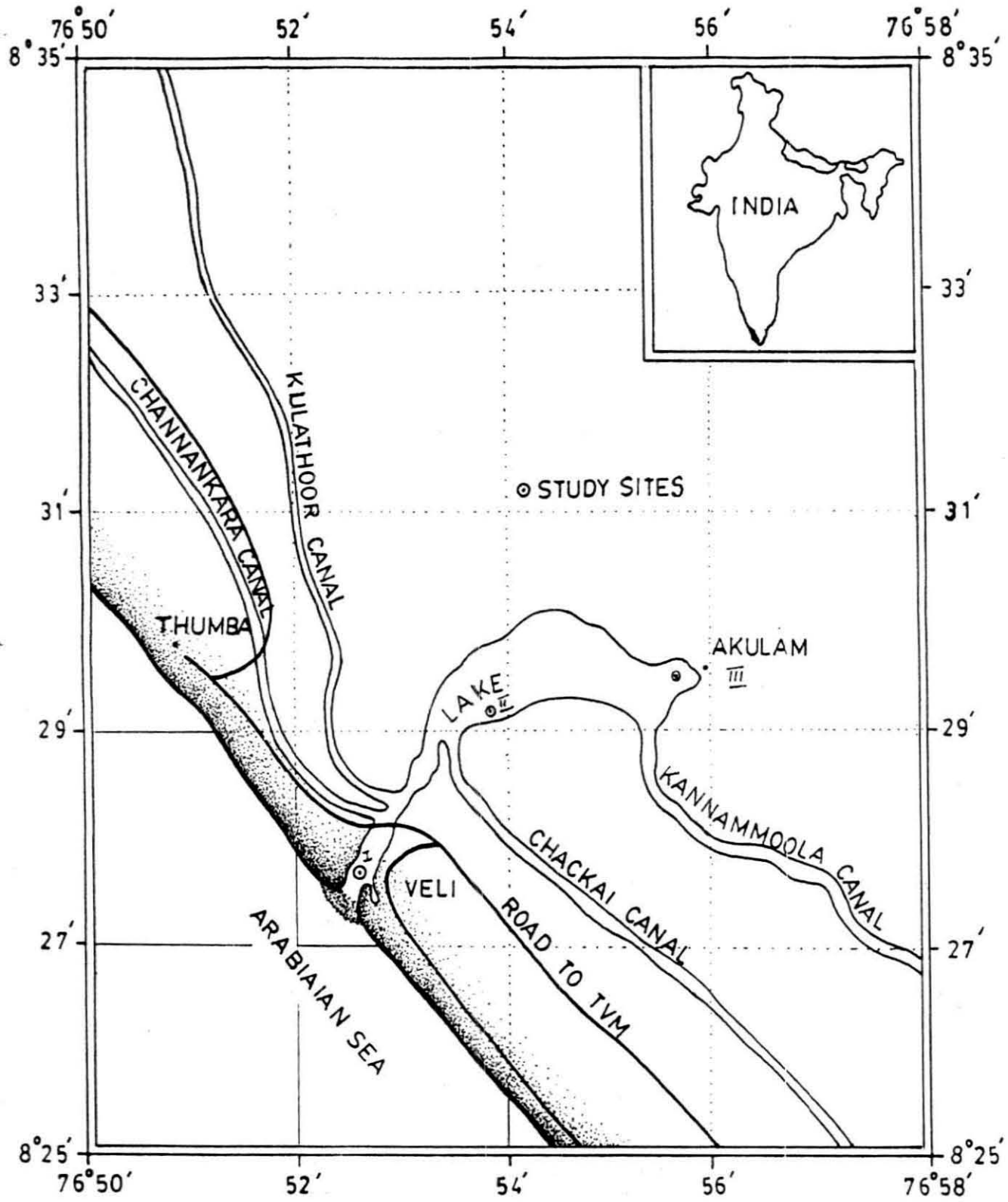


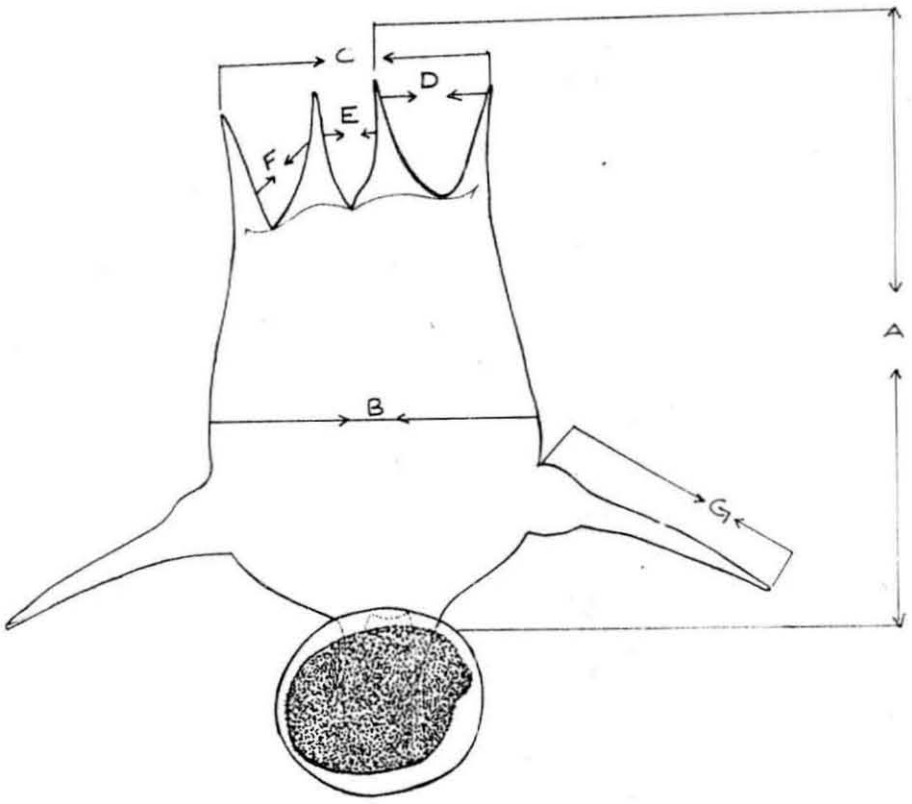
PLATE 2

A view of Veli-Aakulam estuary at Station 1

A view of Veli- Aakulam estuary at Station 2

A view of Veli-Aakulam estuary at Station 3

FIGURE 3: MORPHOMETRIC MEASUREMENTS OF BRACHIONUS



A - LORICA LENGTH
B - LORICA WIDTH
C - DISTANCE BETWEEN LATERAL SPINES
D - DISTANCE BETWEEN MEDIAN & LATERAL SPINES
E - DISTANCE BETWEEN MEDIAN SPINES
F - DISTANCE BETWEEN SPINES
G - LENGTH OF POSTERO-LATERAL SPINE

Fig. 4: *Platyias quadricornis* (Ehrenberg)

Fig. 5: *Platyias leloupi* Gillard

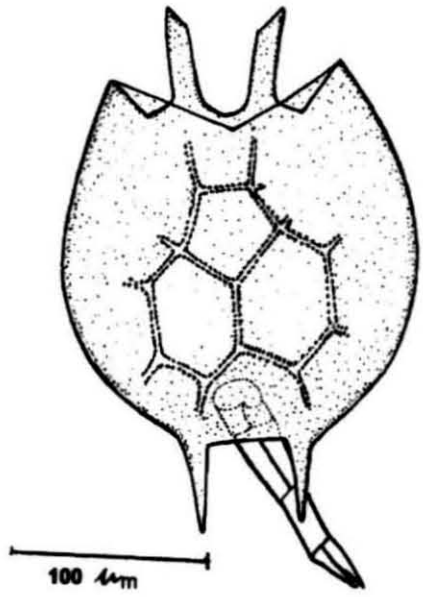


Fig : 4

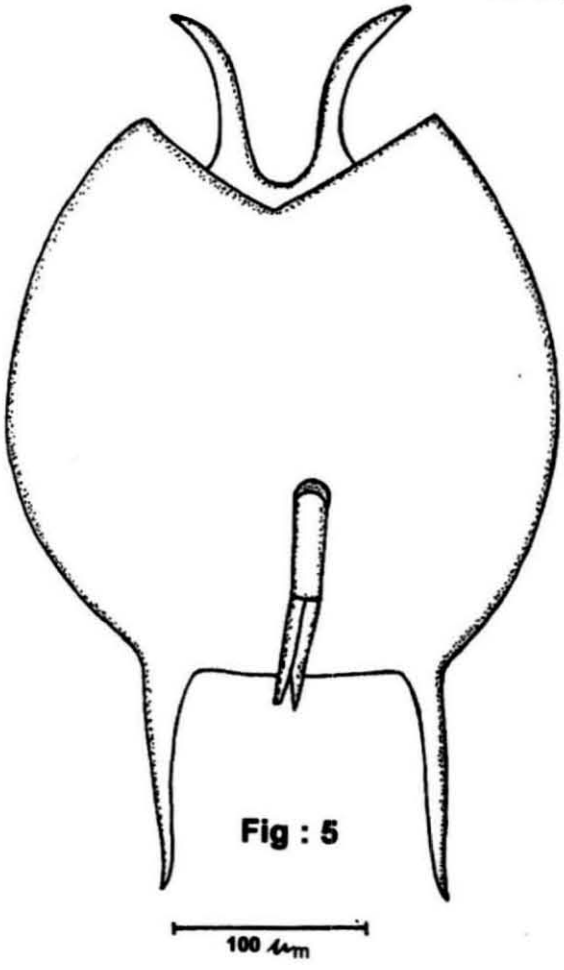


Fig : 5

Fig. 6 - 8: *Brachionus angularis* Gosse

Figs. 9 -11: *B. angularis f. aestivus* Skorikov

Figs. 12 -13: *Brachionus budapestinensis* Daday

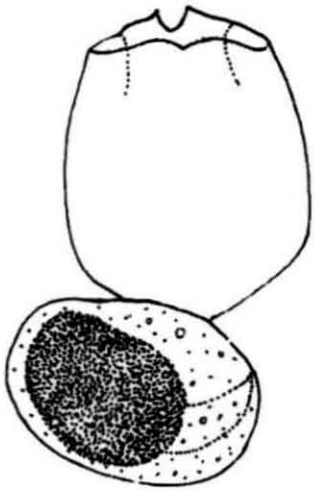


Fig : 6

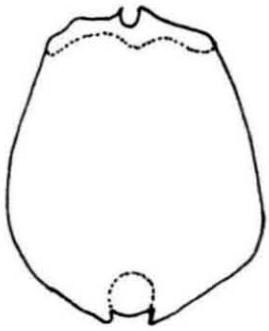


Fig : 7

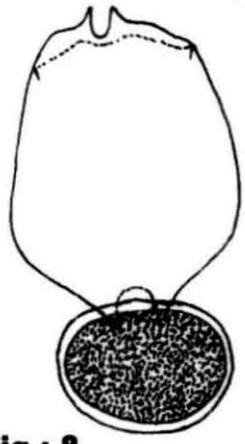


Fig : 8

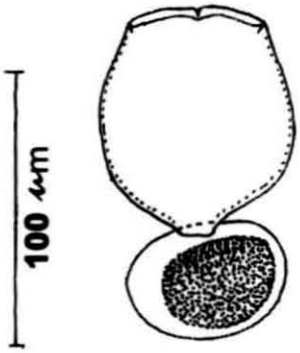


Fig : 9

Fig : 10

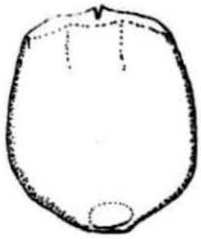


Fig : 11

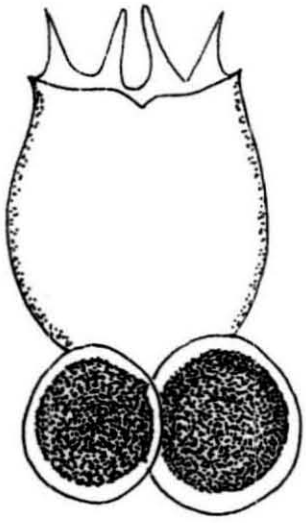


Fig : 12

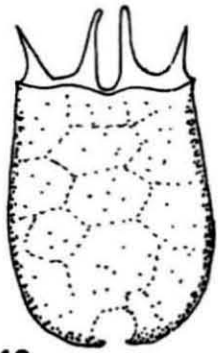


Fig : 13

Fig. 14: *Brachionus calyciflorus f. typica* Pallas

Fig. 15: *B. calyciflorus f. heterospina* Saksena

Fig. 16: *B. calyciflorus f. asymmetrica* Koste

Fig. 17: *B. calyciflorus f. dorcas* Gosse

Fig. 18: *B. calyciflorus f. anuraeiformis* Brehm

Fig. 19: *B. calyciflorus f. forficula* Rudescu

Fig. 20: *B. calyciflorus f. amphiceros* Ehrenberg

Fig. 21: *B. calyciflorus f. monstruosa* de Ridder

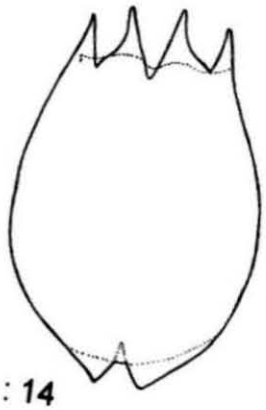


Fig : 14

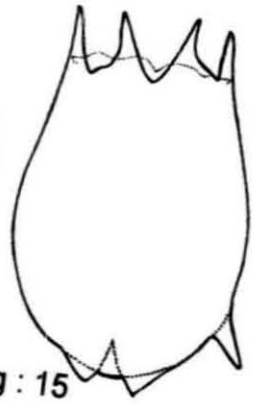


Fig : 15

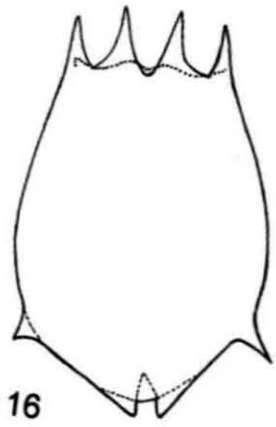


Fig : 16

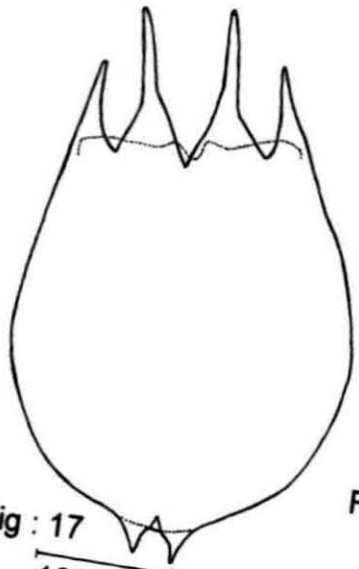


Fig : 17

100 µm

Fig : 18

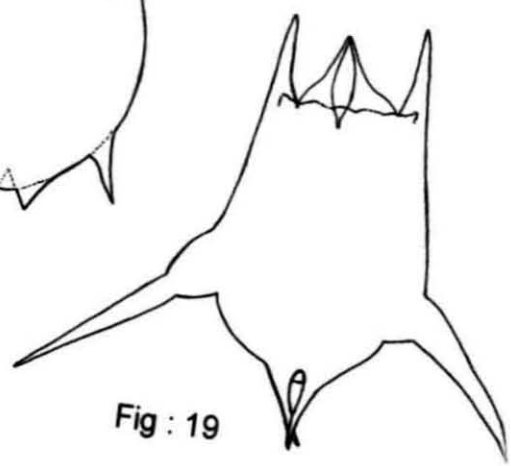


Fig : 19

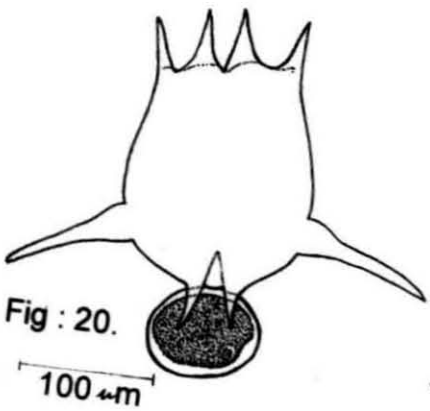


Fig : 20.

100 µm

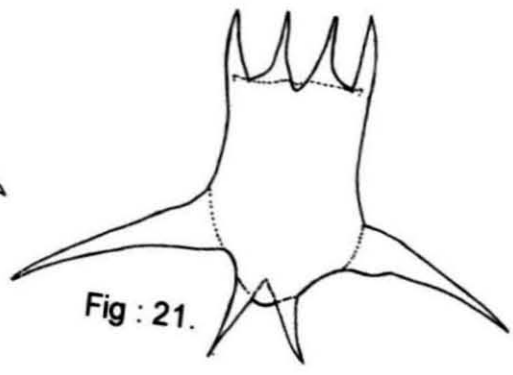


Fig : 21.

Fig. 22: *B. calyciflorus borgerti f. brycei* de Beauchamp

Fig. 23: *B. calyciflorus borgerti f. asymmetrica* f. nov.

Figs. 25 - 26: *B. calyciflorus borgerti f. willeyi* Apstein

Fig :22.

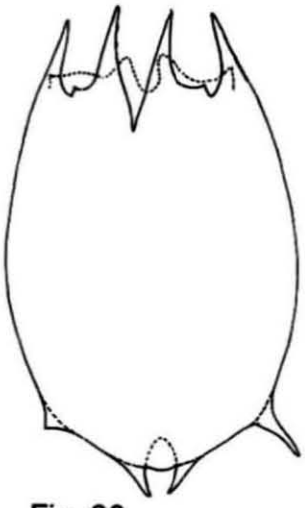
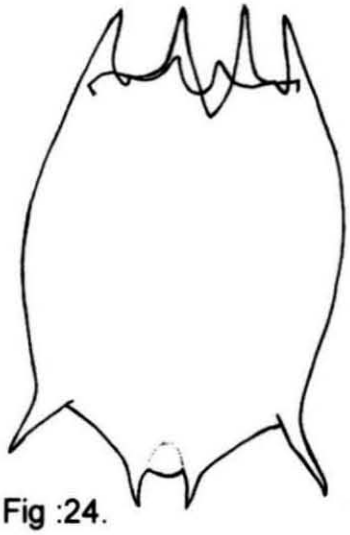


Fig :23.



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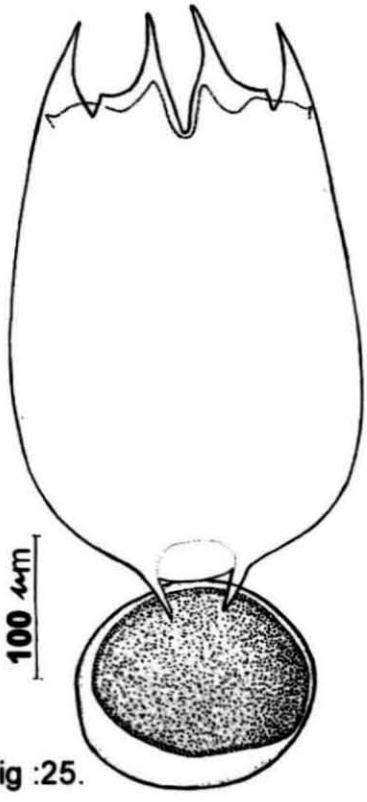

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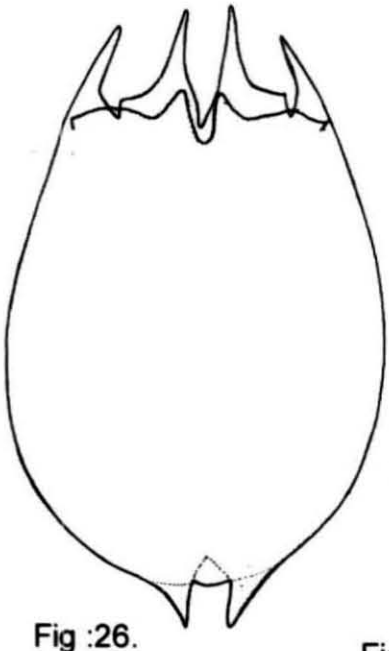


Fig :26.

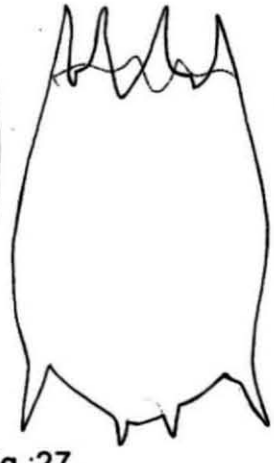


Fig :27.

Fig. 28: *Brachionus caudatus f. majusculus* Ahlstrom

Figs. 29 & 31: *B. caudatus f. apsteini* Ahlstrom

Fig. 30: *B. caudatus f. vulgatus* Ahlstrom

Fig. 32: *B. caudatus f. personatus* Ahlstrom

Figs 33-35: *Brachionus dichotomus reductus* Koste & Shiel

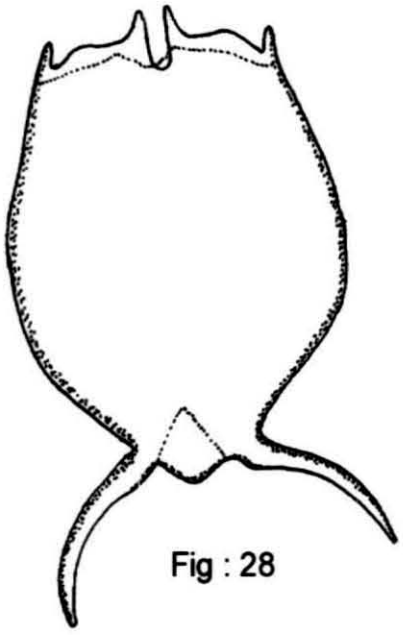


Fig : 28

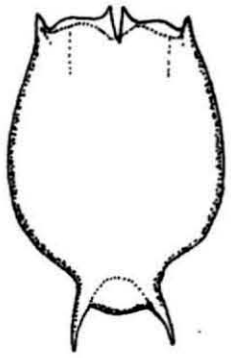


Fig : 29

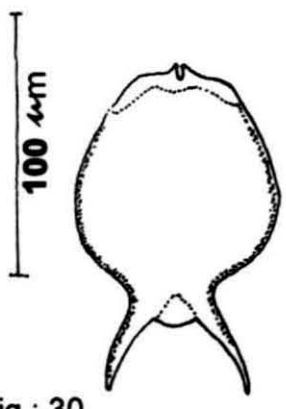


Fig : 30

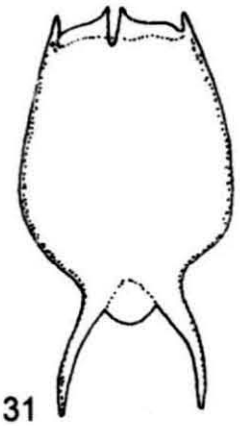


Fig : 31

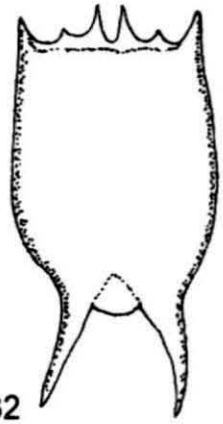


Fig : 32

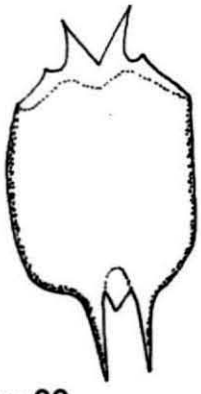


Fig : 33

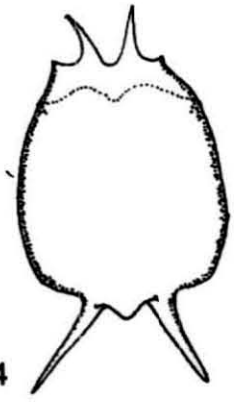


Fig : 34

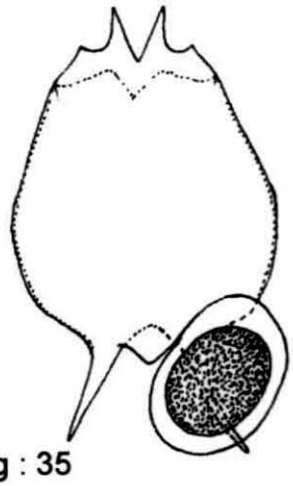


Fig : 35

Figs. 36-37: *Brachionus falcatus f. β* Apstein

Fig. 38: *B. falcatus f. lyratus* Lemmerman

Fig. 39: *B. falcatus f. hamatus* Lemmerman

Fig. 40: *Brachionus patulus* (Müller)

Fig. 41: *Brachionus kostei* Shiel

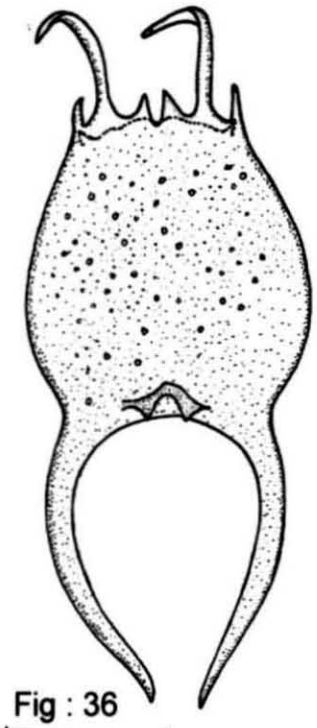


Fig : 36

100 µm

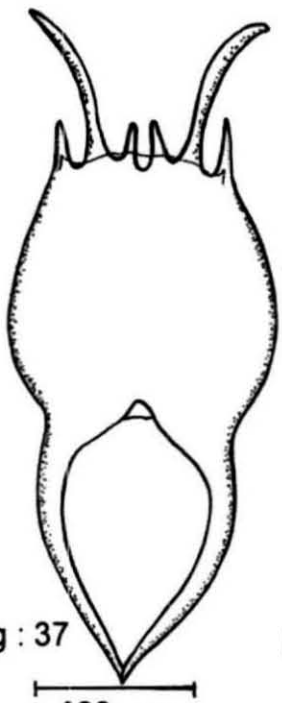


Fig : 37

100 µm

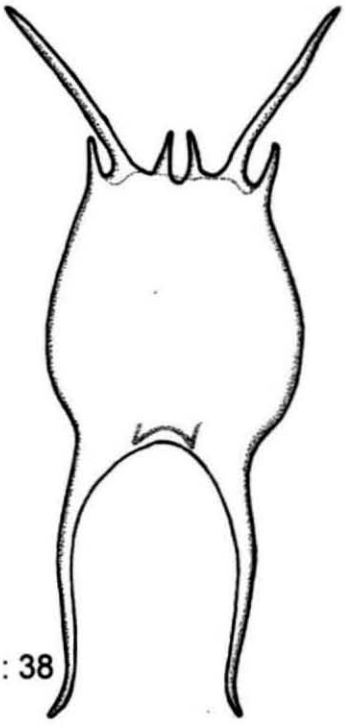


Fig : 38

100 µm

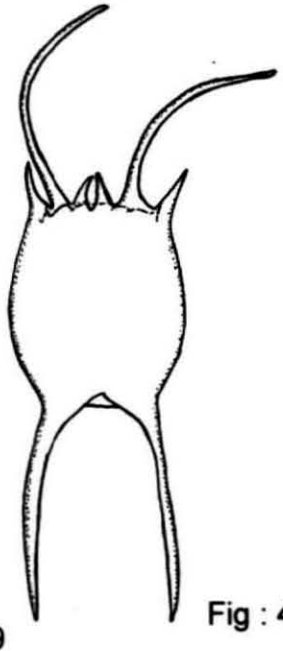


Fig : 39

100 µm

Fig : 40.

100 µm

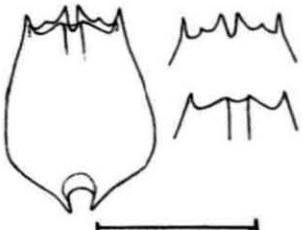


Fig : 41.

100 µm

Figs 42-43: *Brachionus rubens* Ehrenberg

Fig. 44: *Brachionus urceolaris f. irregularispina* f. nov.

Fig. 45: *B. urceolaris nilsoni* (Ahlstrom)

Figs 46-47: *B. urceolaris* Müller

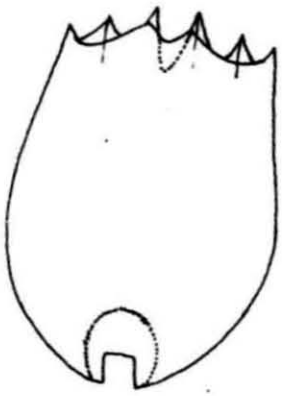


Fig : 42

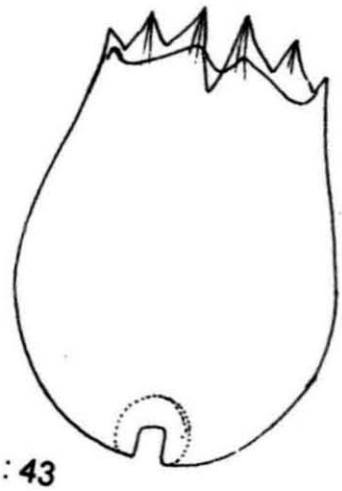


Fig : 43

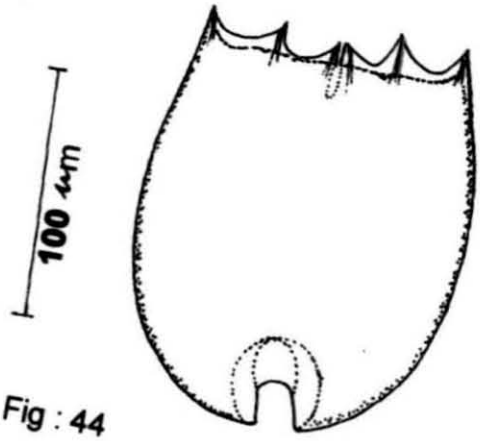


Fig : 44

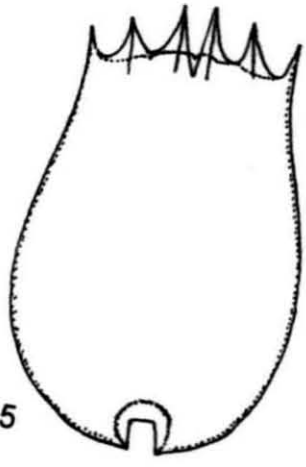


Fig : 45

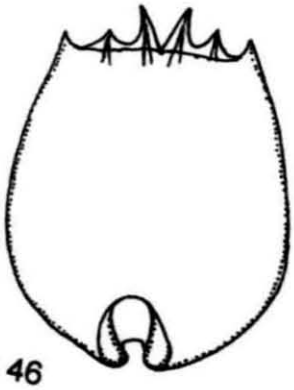


Fig : 46

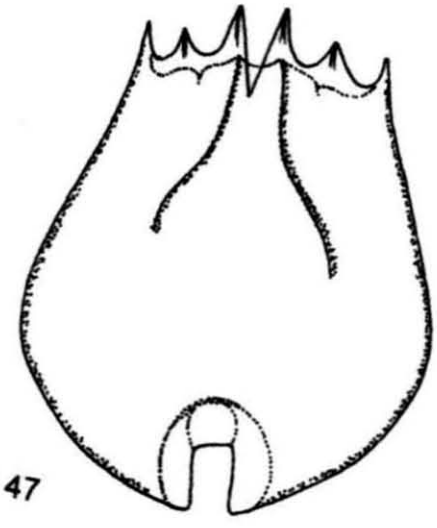


Fig : 47

Figs. 48-53: *Brachionus havanaensis trahea* Murray

Fig. 49: Enlarged view of occipital spines (6 numbers)

Fig. 50: Enlarged view of the mental margin with distinct 'U' sinus

Fig. 51: *B. havanaensis trahea f. ahlstromi* f. nov.

Fig. 52: *B. havanaensis trahea f. asymmetrica* f. nov.

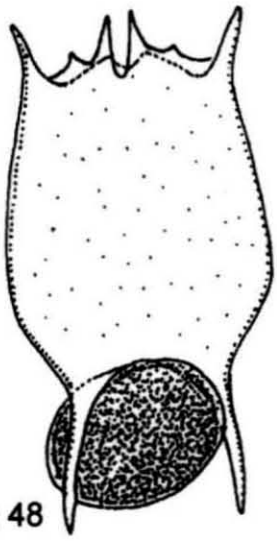


Fig : 48

Fig : 49

Fig : 50

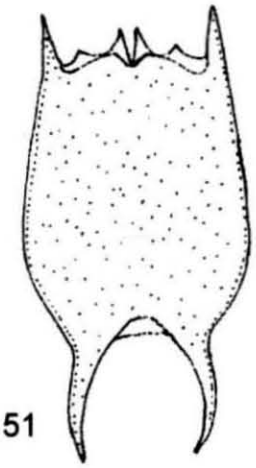
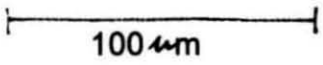


Fig : 51



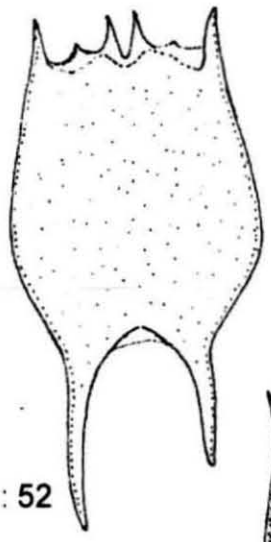


Fig : 52

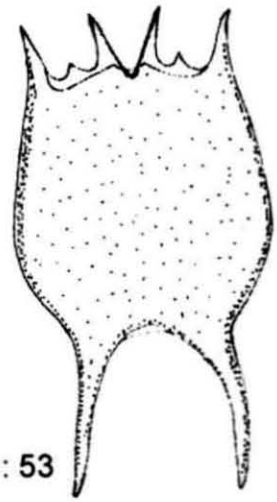


Fig : 53

Fig. 54: *Brachionus quadridentatus f. brevispina* Ehrenberg

Fig. 55: *B. quadridentatus f. monospina* Saksena

Fig. 56: *B. quadridentatus f. divergens* Tschugunoff

Fig. 57: *B. quadridentatus f. melheni* Barrois & Daday

Fig. 58: *B. quadridentatus mirabilis* Daday

Fig. 59: *B. quadridentatus f. curvata* Tschugunoff

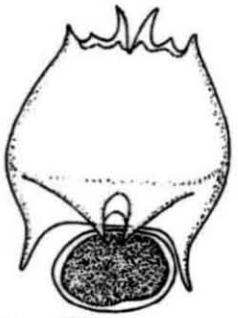


Fig : 54

100 µm

Fig : 55

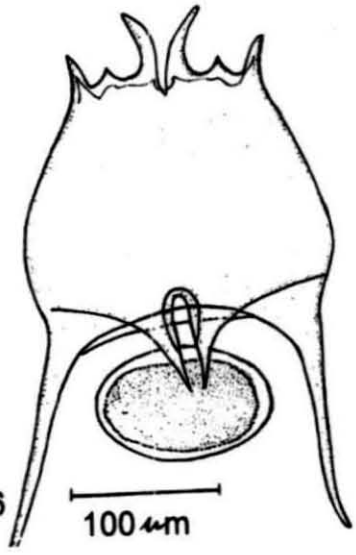


Fig : 56

100 µm

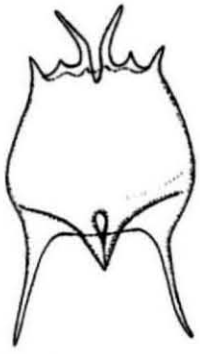
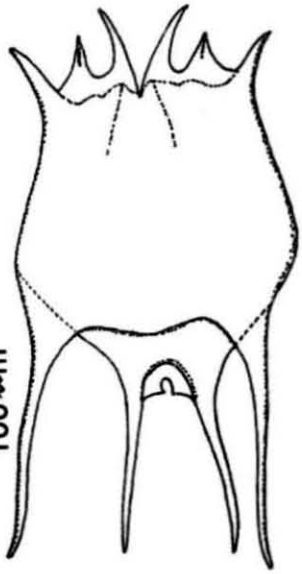


Fig : 57



100 µm

Fig : 58

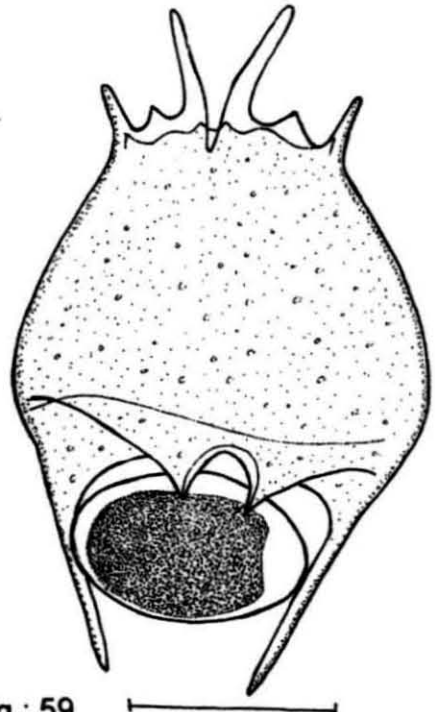


Fig : 59

100 µm

Figs 60-73:	*Brachionus plicatilis* Müller
Fig. 62:	*B. plicatilis f. mülleri* Ehrenberg
Figs. 63-64:	*B. plicatilis f. hepatotomus* Fadeew
Figs. 67-68: 71 & 73	*B. plicatilis f. decemcornis* Fadeew
Figs. 69-70: & 72	*B. plicatilis f. ovalis* f. nov.

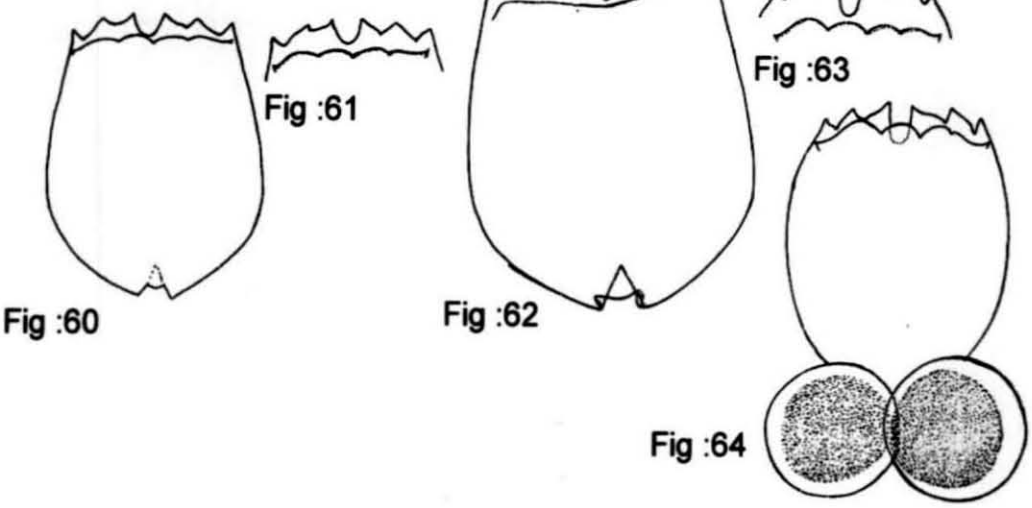


Fig :60

Fig :61

Fig :62

Fig :63

Fig :64

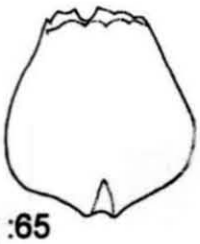


Fig :65

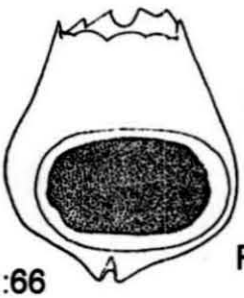


Fig :66

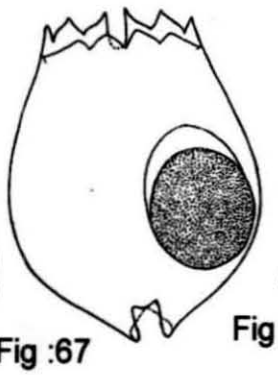


Fig :67


Fig :68

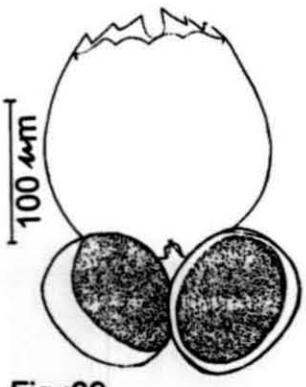


Fig :69

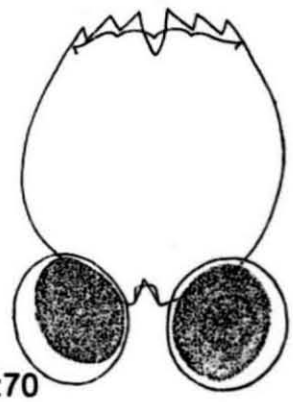


Fig :70

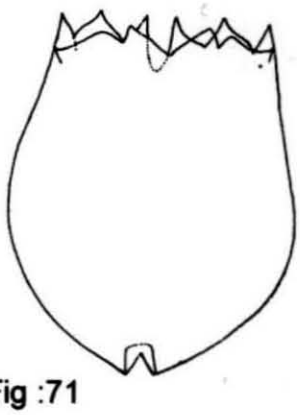


Fig :71

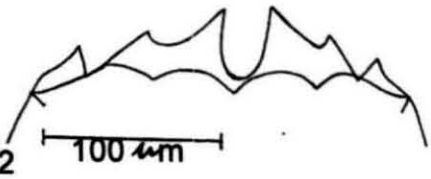


Fig :72


Fig :73

Figs. 74-90:	*Brachionus murray* Murray
Figs. 80-81: & 83	*B. murray f. ecornis* Fadeew
Figs 82-83:	*B. murray f. longicornis* Fadeew
Figs. 89-90:	*B. murray f. divergispina* f. nov.

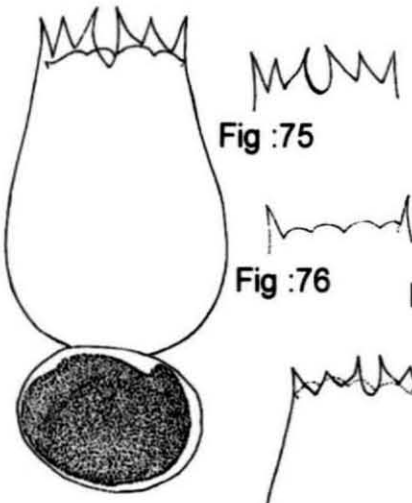


Fig :74

Fig :75

Fig :76

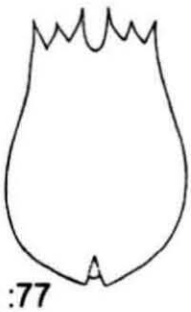


Fig :77

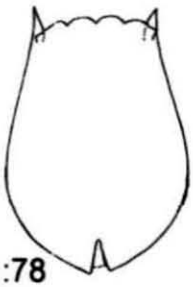


Fig :78

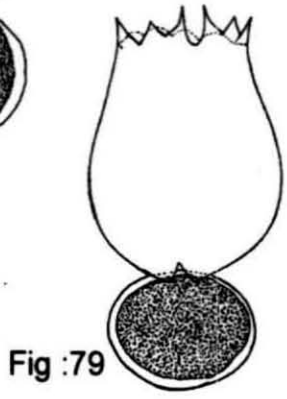
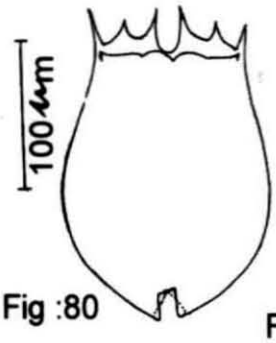


Fig :79



100 um

Fig :80

Fig :81

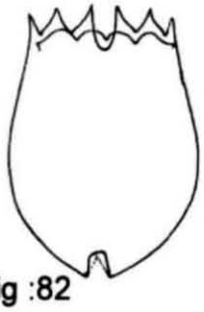


Fig :82

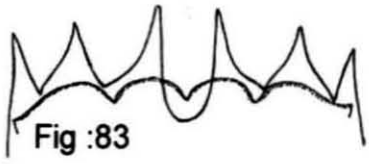


Fig :83

100 um

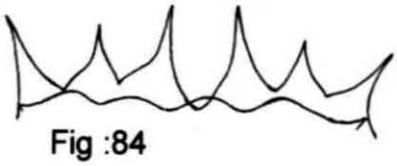


Fig :84

100 um

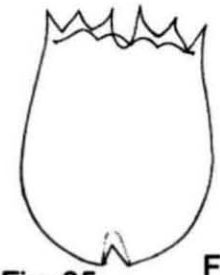


Fig :85

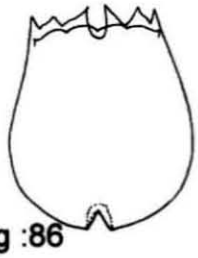


Fig :86

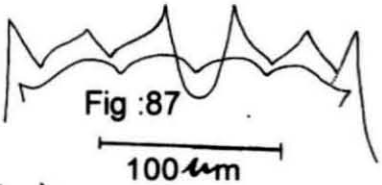


Fig :87

100 um

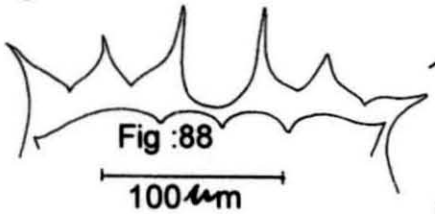


Fig :88

100 um

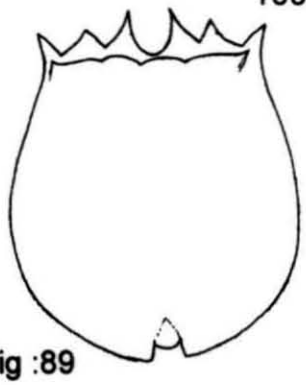


Fig :89

Fig :90

Figs. 91-99: *Brachionus rotundiformis* Tschugunoff

Fig. 94: Enlarged view of the occipital portion showing the distinct mental margin with elevated lateral projections

Figs. 97-99: *B. rotundiformis f. semicircularis* f. nov.

Fig :94

100 µm

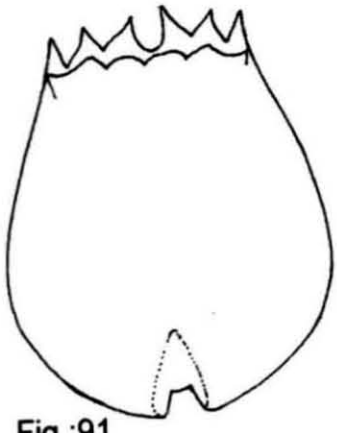


Fig :91

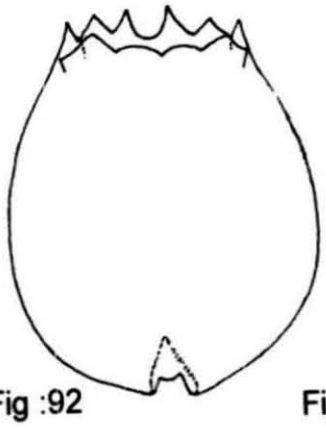


Fig :92

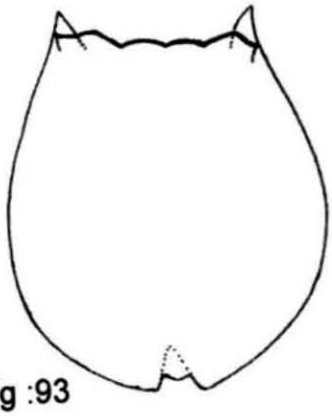
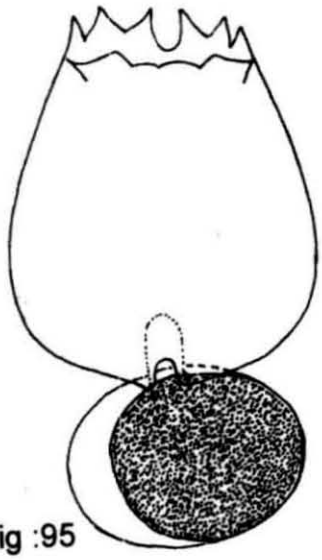


Fig :93



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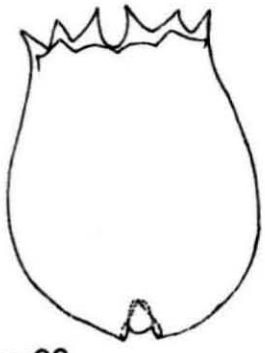

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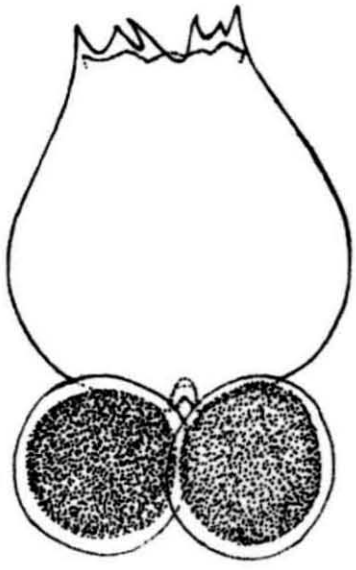

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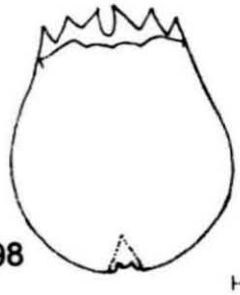


Fig :98

100 µm

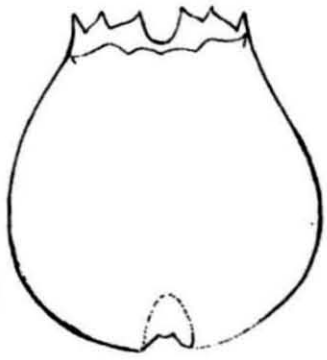


Fig :99

Fig. 100: *Keratella cochlearis* (Gosse)

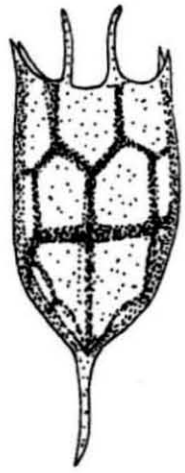
Fig. 101: *K. cochlearis f. tecta* (Lauterborn)

Fig. 102: *K. cochlearis f. recurvispina* (Jägerskiöld)

Fig. 103: *Keratella tropica f. asymmetrica* (Barrois & Daday)

Fig. 104: *K. tropica f. typica* (Apstein)

Fig. 105: *K. tropica f. aspina* (Fadeev)



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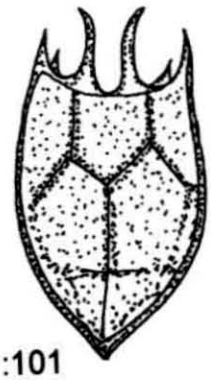

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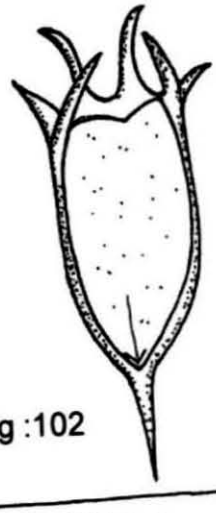


Fig :102

Fig :103

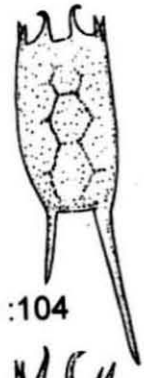


Fig :104

Fig :105

100 µm

100 µm

CHAPTER 2

DISTRIBUTION, ABUNDANCE AND DIVERSITY OF ROTIFERS IN RELATION TO HYDROGRAPHY AND FOOD AVAILABITY FROM TWO SELECTED BIOTOPES

INTRODUCTION

Rotifers form the essential structural and functional components of pelagic communities in different water bodies. In lakes and estuaries, rotifers can be responsible for 95% of the total zooplankton biomass during certain periods (Telesh, 1995; 1998). These organisms in their presence or absence and in all features of their phenotype and physiology, serve as an index of their environment. Rotifer fauna plays a crucial role in the food chain of aquatic systems, since they are an excellent food source for various fish larvae and other aquatic invertebrates. Thus, in view of their significance in the aquatic system, an understanding of their pattern of distribution, intensities, seasonal fluctuations and relationship with the different biotic and abiotic environmental factors is of utmost importance before going into the details of the biological aspects.

Environmental variations, both in space and time, are universal in nature. Most researches in population ecology attempt to unravel the consequences of these variations to understand the forces moulding the occurrence, distribution and potential of the species under investigation. Rotifers are exposed to a variety of ever-changing physical, chemical and biotic factors of dynamic environment they inhabit. However, like any other aquatic organism, due to their minute size, high population turnover rate and comparatively shorter lifespan than other large zooplankters, rotifers are highly sensitive and they immediately respond either negatively or positively to the environmental changes. Some of these changes are relatively minor, and the individuals in the population adjust either by acclimatization, modification of their position in the water column, or changes in behavior. Other environmental changes are more severe and eliminate the rotifer species from the ecosystem.

The ecology of rotifers was widely investigated all over the world. Observations on the distributions and abundance of rotifers have been made

since the seventeenth century. Ahlstrom (1933, 1934, 1938), Edmondson (1944), Beach (1960) and Hutchinson (1967) studied the rotifer community and its relationship with changes in physico-chemical parameters and showed that tolerance for various ecological factors influencing the population dynamics of a rotifer species varies considerably with its geographical distribution and local climatic conditions. Green (1972) found that abiotic environmental factors determined occurrence and fluctuations in the density of species in an ecosystem.

Galkovskaya (1987) studied planktonic rotifers and their relationship with temperature variations. He opined that temperature influenced other ecological parameters of water bodies, which in turn affect rotifer abundance and distribution. The studies conducted by Bērziņs and Pejler (1987, 1989) Miracle *et al.* (1987), Esparicia *et al.* (1989) Mikschi (1989), Beatriz (1998) and King and Serra (1998) revealed that abiotic environmental factors such as temperature, salinity, pH and dissolved oxygen had a direct influence on the rotifer community and their distribution in natural habitats.

The influence of biotic factors on the occurrence, rotifer density and importance of algal feed was investigated by Erman (1962a, b), Gliwicz (1969), Radwan (1976), Dumont (1977), Pourriot (1977), Pejler (1983) and Haberman and Sudzuki (1998). They found that the availability of potential food organisms such as algae, bacteria etc. had a direct influence on the occurrence and abundance of rotifer species or groups in a particular environment.

Rotifers have invariably figured in Indian publications relating to general plankton ecology, and are reported as a dominant or subdominant component of freshwater zooplanktonic communities. A majority of the ecological studies on rotifers were conducted in West Bengal, Utter Pradesh and Jammu & Kashmir. Earlier workers such as George (1961, 1966b), Arora (1966d, e), Michael (1968, 1985), Nayar (1970), Vasisht and Sharma (1976) and Jyoti

and Sehgal (1979) studied the impact of the rotifer community upon abiotic environmental changes and the studies had showed that environmental factors like temperature, pH, dissolved oxygen and alkalinity had a significant influence on the occurrence, abundance and seasonal fluctuations in a rotifer community in different water bodies.

George (1966) observed a summer periodicity of rotifers in tropical ponds, whereas Moitra and Bhowmick (1968) recorded a regular succession of rotifer species in water bodies. Similarly, the observations on ecology of rotifers in India by Qadri and Yousuf (1976, 1980), Saksena and Sharma (1981), Rao (1982), Saha and Pandit (1986), Mishra and Saksena (1990), Amita and Saksena (1992) and Archana (1998) have further corroborated the earlier studies. It is evident from the above studies that the ecological investigations have concentrated only on limited abiotic factors namely the temperature, pH and dissolved oxygen.

Though most of the investigations were on the rotifers of freshwater environments, studies on rotifers in the estuaries of India are very limited. The important observations are those of Rao and Chandra Mohan (1984), Ramesh Konnur and Jayapaul Azariah (1986), Govindasamy (1988) and Govindasamy and Kannan (1991) and their studies revealed that certain abiotic factors had a significant influence on the occurrence, abundance and distribution of rotifers in estuaries.

Detailed ecological investigations on rotifers from estuaries of Kerala are very few. While investigating the general plankton ecology of different habitats by Nair et al. (1984), Nair and Abdul Aziz (1987), Shibu (1991), Harikrishnan (1993), Bijoy Nandan (1991), Bijoy Nandan and Abdul Aziz (1994) and George Thomas (1996) have observed the availability and abundance of rotifers in the estuarine habitats; Anuradha Rammohan (1996) studied the zooplankton of Kadinamkulam Lake, highly polluted due to retting

of coconut husk, and this study revealed that even in highly polluted areas rotifers were available.

Gopakumar (1998) studied the occurrence, abundance, and seasonal distribution of rotifers in general and the haline rotifer, *B. plicatilis* in particular at different estuaries of varying salinity. According to him, salinity was the chief limiting factor for the occurrence and distribution of rotifer communities in the estuaries of Kerala.

It was also clear from the above that the rotifers form an important component of the plankton fauna of different estuaries of Kerala while the ecology of this group remains still poorly understood, despite their significant contribution to the aquatic production. Furthermore, most of the species belonging to the genus *Brachionus* are considered highly suitable first live-feed for various fish and shellfish larvae. Hence, a thorough understanding of the general ecology of the rotifers is a must to formulate a suitable technology for mass production of the potential species. Keeping this in view, two different kinds of estuaries in Kerala were selected for the present study and the occurrence, distribution, diversity and seasonal fluctuations of rotifers in were investigated to study their relationship with the ecological parameters.

DISCRIPTION OF STUDY AREA

The State of Kerala characterized by a number of lagoons and backwaters associated with estuaries, constitute an important source of inland fishery resource. These backwaters and estuaries also serve as a nursery ground for various finfish and shellfish larvae by providing food and shelter. Thus estuaries and backwaters play an important role in the economy, resource enhancement and diversity of the State. The first site chosen for the present study was Poonthura, a low-saline oligotrophic estuary situated 3 - 4 km west of Trivandrum City on the Kerala coast, between latitudes 8°25' N and 8°30' N and longitudes 76°55' E and 77°00' E (Fig.1, Pl.1). The total

length of the estuary is 4.35 km and its mean width 0.1 km progressively narrowing from its barmouth to the interior part. The estuary formed by Parvathy Puthanar and Karamana Rivers and is roughly circular in shape enclosing a landmass called Edayar. These two rivers are chiefly influenced the water quality of this estuary. Unlike large backwaters such as the Vembanad and Ashtamudi Lakes, it has no permanent connection with the sea but separated by a narrow strip of sandy beach in between. During the monsoon period the barmouth breaks open for a brief period, thus establishing connection with the sea. The two sites were selected for the present study, based on the decreasing trend of salinity from the barmouth to the interior part of the estuary.

The next site chosen for the present study was the Veli - Aakulam estuary (an eutrophic estuary), confined to the southern part of the State and situated 5 km north-west of Trivandrum city (Fig. 2, Pl. 2), between latitude 8°25' N and 8°35' N and longitude 76°50' E to 76°58' E. The lake is about 1 km long and 0.3 km broad, progressively widening from the barmouth to the eastern part. It is connected to the Kadinamkulam Lake in the north, the Aakulam Lake in the east and the Chackai canal in the south. Collections were made from three stations depending on salinity fluctuations from the barmouth to the interior part of the estuary (Aakulam). Of these three stations, Station 1 is close to the sea. When the sand bar separating the water body from the sea is cut open during flood times, it attains estuarine characteristics for short periods every year, and this station is generally characterized by high salinity. Station 2 is about 0.5 km north-east of Station 1 whereas Station 3 is the interior most segment of the Veli - Aakulam estuary with the least salinity and is vastly covered by weeds such as *Eichornia* sp., *Salvinia* sp. and was very shallow during a greater part of this study.

MATERIAL AND METHODS

Rotifers and water samples were collected from Poonthura and Veli-Aakulam estuaries. Fortnightly zooplankton collections were made by taking

horizontal hauls using bolting silk net (mesh size 70 μm; mouth area 0.16 m^2) with an attached digital flowmeter (Model No. 438110). The plankton samples were preserved in 4% formaldehyde and biomass determined by sedimentation method. Depending on the rotifer concentration, either the whole sample or a part (1 ml) of it was counted in a Sedwig - Rafter Counting Tray inorder to determine the numerical abundance of rotifers. The values for the whole sample were computed as number per m^3 of water.

Standard methods were followed for the analyses of the surface water samples and the hydrographic data were recorded. Surface water temperature at the time of collections was measured using a centigrade thermometer. The hydrogen-ion concentration (pH) of the water was estimated with the help of an 'Elico' pH meter.

Samples for the determination of dissolved oxygen were collected separately in 125 ml stoppered glass bottles, taking precautions to avoid the entry of air bubbles. The samples were fixed on the spot using manganous sulphate and alkaline potassium iodide and estimated in the laboratory by the Winkler's method (Strickland and Parson, 1972) and the values were expressed in mg/l.

For the estimation of salinity, samples were collected in polythene bottles and the values were estimated titrimetrically by the Mohr's method, and expressed in ppt (‰). For nutrients analysis, water samples were collected in polythene bottles and stored in a refrigerator till the time of analysis. Inorganic Phosphate-phosphorus, Nitrate-nitrogen, Nitrite-nitrogen and Silicate-silicon were estimated adopting standard procedures described by Strickland and Parson (1972), and the values were expressed in μg/l.

Water samples for the estimation of hydrogen sulphide were taken in 300 ml BOD bottles, treated with cadmium chloride solution and the precipitate were allowed to settle. After 48 hours, the dissolved hydrogen

sulphide was estimated using the method of Golterman and Clymo (1978) in which the precipitated sulphide is dissolved in a known volume of iodine solution and hydrochloric acid and titrated against standard sodium thiosulphide solution.

Free-carbon dioxide and total alkalinity in the water samples were estimated in the laboratory following the standard methods of APHA (1998). Samples for the estimation of free-carbon dioxide, total alkalinity and ammonia-nitrogen were collected in polythene bottles. Free-carbon dioxide and Ammonia-nitrogen were estimated immediately after the sample collection inorder to minimize the error between the collection and analysis. Samples for the estimation of total alkalinity were preserved with 1 ml of chloroform and stored in a refrigerator till the time of analysis. Free-carbon dioxide in the samples was estimated by adding a few drops of phenolphthalein (indicator) and titrated against standard sodium hydroxide solution and values were expressed in mg/l.

Ammonium ions were estimated by adopting the standard procedure described by Bolleter *et al.* (1961) and the values were expressed as μg/l. Total alkalinity was estimated by using methyl orange as indicator and titrating against standard sulphuric acid solution and the values expressed in mg/l.

Correlation co-efficient was worked out by using SYSTAT, version 7.0 to study the relationships between the dominant rotifers and the hydrographic factors. Species diversity index (Shannon and Weaver, 1963), Index of dominance (Simpson, 1949), Species richness index (Menhinick, 1964) and Evenness index (Pie Lou, 1966) were calculated using the following expressions:

Index of dominance (C) = $\sum(ni / N)^2$

Where ni = importance value for each species

N= total of importance value.

Species richness of variety indices (δ) = (S -1) / log N

Where S = number of species

N = number of individuals

Shannon – Weaver's index of species diversity ($\bar{H}$)

$(\bar{H}) = - \Sigma(ni / N) \times \log (ni / N)$

Where ni = importance value for each species

N = total importance of values

Evenness index (e) = $\bar{H}$ / log S

Where $\bar{H}$ = Shannon- Weaver's index

S = number of species.

To facilitate interpretation, the data obtained were analyzed seasonwise as follows: February to May (Pre-monsoon), June to September (Monsoon) and October to January (Post-monsoon), based on rainfall data from the Meteorological Department, Trivandrum.

RESULTS

Data on hydrography, rotifer abundance and distribution in the Poonthura and Veli-Aakulam estuaries revealed the following relationship between the parameters investigated.

Poonthura: A low-saline Oligotrophic Estuary

Environmental Conditions: Figure 106a-m showed the monthly variations in rainfall and selected hydrographic parameters at two stations in Poonthura estuary during 2000-2001. The annual rainfall varied from 2.40 mm (January) to 451.78 mm (October) during the period of study (Fig. 106a).

The surface water temperature fluctuated from a minimum of 26.00 °C (June and December) to a maximum of 31.00°C (May) at Station 1 and from

26.00°C (June) to 31.20°C (May) at Station 2(Fig. 106b). In the present study, maximum temperatures were recorded during the pre-monsoon season and minimum during the monsoon season in both stations. Thus, there was a lowering of the temperature corresponding to the onset of the south-west monsoon; subsequently there was an increase, reaching the highest values in the pre-monsoon months.

The monthly average of salinity values ranged from 0.93 ppt (June) to 5.47 ppt (April) at Station 1 and from 0.15 ppt (September) to 0.94 ppt (January) at Station 2 during the period of study (Fig. 106c).

Throughout the study, the pH of the surface water at Station 1 showed an oscillation towards the neutral to alkaline side whereas at Station 2, the oscillation of pH was towards the acidic to the neo-neutral side. The hydrogen ion concentration (pH) was the minimum in September at Station 1 (6.04) and at Station 2 (5.10). Maximum pH was observed in May (7.42) at Station 1 and in March (7.01) at Station 2 (Fig. 106d).

The total alkalinity concentration varied from 7.12 mg/l (September) to 54.70 mg/l (February) at Station 1 and from 2.94 mg/l (September) to 42.84 mg/l (March) at Station 2 (Fig. 106e). The highest fluctuation in total alkalinity was observed during the monsoon season (July - September) and the least was during pre-monsoon (Feb - May) period. However, the low values of total alkalinity together with low pH and low dissolved oxygen values given in Fig106c, d & e revealed that total alkalinity had a direct relation with other variables during the period of study.

The monthly mean values of dissolved oxygen varied from a minimum of 1.52 mg/l (September) to a maximum of 5.30 mg/l (May) at Station 1 and from 0.93 mg/l (September) to 4.77 mg/l (March) at Station 2 (Fig. 106f). In general, the dissolved oxygen values showed a minimum value during the

monsoon period and comparatively higher values during the pre-monsoon period throughout this study.

The free-carbon dioxide showed a similar distribution pattern during the period of study. The concentrations of free-carbon dioxide in the surface water at Station 1 varied from 1.27 mg/l (May) to 62.72 mg/l (June) and from 5.13 mg/l (March) to 72.62 mg/l (September) at Station 2 (Fig. 106g).

The value for nitrite-nitrogen recorded in June (9.25 μg/l) was the maximum, and in May (0.23 μg/l) was the minimum at Station 1; and it was high in June (10.32 μg/l) and low in March (0.67 μg/l) at Station 2 (Fig. 106h).

The nitrate-nitrogen fluctuated from 0.88 μg/l (May) to 21.83 μg/l (June) at Station 1 and from 1.28 μg/l (February) to 25.35 μg/l (June) at Station 2 (Fig. 106i). Throughout the period of this study, nitrite and nitrate values were higher during the monsoon season than those observed during the post-monsoon and pre-monsoon periods at both the Stations.

Phosphate concentration at Stations 1 and 2 fluctuated from 0.24 μg/l (May) to 4.84 μg/l (June) and from 0.23 μg/l (March) to 7.75 μg/l (June) respectively (Fig. 106j). The concentration of silicate varied from 1.98 μg/l (May) to 31.28 μg/l (June) at Station1 and from 1.83 μg/l (April) to 39.84 μg/l (June) at Station 2 (Fig. 106k). The highest concentration of silicate was observed during both the monsoon and post-monsoon seasons.

The concentration hydrogen sulphide was detectable during the monsoon period at both the stations with a peak in September at Stations 1 (1.50 μg/l) and 2 (2.67 μg/l) (Fig. 106l). It is interesting to note that the highest concentration of hydrogen sulphide was observed in surface waters when pH, dissolved oxygen and total alkalinity recorded low values. The total ammonia-nitrogen (NH_3-N) also showed a similar pattern of fluctuation like free-carbon

dioxide and hydrogen sulphide in the present study. The ammonia-nitrogen concentrations were varying from 0.03 μg/l (May) to 3.41 μg/l (June) at Station 1 and from 0.22 μg/l (March) to 7.34 μg/l (September) at Station 2 (Fig. 106m).

In general, the surface water was clear during the pre-monsoon period but turned highly turbid and opaque during the monsoon period with a heavy land runoff from Karamana River into the estuary. Comparatively large number of green algae, especially *Scenedesmus* sp. was noted in April and May. However, no algal bloom was observed at any time during this study.

Rotifer abundance and species composition

In Poonthura estuary, the population density was the maximum in April (17427/m^3) and the minimum in September (73/m^3) at Station 1l. At Station 2, the maximum and minimum values for total rotifer population density were recorded in March (5387/m^3) and in June (13/m^3). Also a secondary peak period was noticed in February (14821/m^3) at Station 1 and in January (1438/m^3) at Station 2 (Table 1 & 2). Considering the relationship between the total rotifer density and hydrographic parameters, it was found that variables such as total alkalinity ($p<0.01$) and dissolved oxygen ($p<0.01$) were significantly correlated with rotifer abundance in both the stations. Similarly, the total rotifer density showed a significant negative relationship with the phosphate and silicate concentrations at both the stations (Table 3 & 4). However, most of the variables showed a significant influence on total rotifer density at Station 1

Data on the abundance and seasonal fluctuations of various rotifers belonging to different families are presented in Tables 5 and 6. A total of 36 rotifers belonging to 14 families were recorded from Poonthura estuary. Of these, the family Brachionidae was represented by the highest number of 17 species, followed by Lecanidae (six species), Filiniidae (three species) and Lepadellidae (two species). Families such as Epiphanidae, Asplanchnidae,

Testudinellidae, Synchaetidae, Mytilinidae, Trichotriidae, Euchlanidae and Hexarthridae were represented by one species each.

Brachionidae: This family represented by three genera, namely *Brachionus*, *Keratella* and *Platyias*. Of these the genus *Brachionus* formed the most dominant component throughout the period of study at both stations. The different species of this family were *B. angularis*, *B. calyciflorus*, B. *caudatus*, *B. dichotomous reductus*, *B. falcatus*, *B. kostei*, *B. patulus*, *B. plicatilis*, B. *havanaensis trahea*, *B. quadridentatus*, *B. murray (B. rotundiformis* 'S' type*)*, *B. rubens* and *B. urceolaris* (Genus: *Brachionus*), *Keratella cochlearis*, *K. tropica* (Genus: *Keratella*), *Platyias leloupi* and *P. quadricornis* (Genus: *Platyias*). Among the brachionid species *B. angularis* was observed in all the seasons with peak abundance during the pre-monsoon at Stations 1 and 2. The maximum numerical abundance of this species was observed in April at Station 1 and in May at Station 2, whereas the occurrence of *B. calyciflorus* was restricted to the pre-monsoon period and after a time lag, it reappeared in January at both the stations with a maximum population density in March. *B. plicatilis* occurred in almost all the seasons, recording a maximum abundance in July at Station 1 and in May at Station 2. However, the maximum number of *B. caudatus, B. falcatus, B. quadridentatus, B. urceolaris, B. havanaensis trahea* and *B. rubens* were observed only during the pre-monsoon period at both the Stations. The rotifers *B. dichotomus reductus* and *B. kostei* were new records to India. *B. kostei* was observed only in the month of February at Station 2 while it was not observed at the Station 1. *B. dichotomus reductus* was observed during the pre-monsoon with a peak in May ($48/m^3$) at Station 1 and in March ($52/m^3$) at Station 2. The haline rotifer, *B. murray* was present only at Station 1 while it was absent at Station 2 during the period of this study. However, the numerical abundance of this species was very low at Station 1. Among the *Keratella* species, *K. cochlearis* occurred in all the months while *K. tropica* was observed only during the pre-monsoon and post-monsoon seasons at Stations 1 and 2. Similarly *Platyias quadricornis* and *P. leloupi* (Genus:

Platyias) occurred only in August at Station 2 and were not recorded at Station 1.

Lecanidae: The different species represented in this family were *Monostyla bulla*, *M. quadridentata*, *Lecane curvicornis*, *L. luna*, *L. ludwigi* and *L. leontina*. Of these, *M. bulla* was observed in March with its maximum density of 179/m^3 at Station 1 and in August (70/m^3) at Station 2, whereas *M. quadridentata* recorded its highest numerical abundance in March at Station 2. *Lecane curvicornis* and *L. leontina* were observed at both the stations while *L. luna* and *L. ludwigi* were observed at Station 2.

Filiniidae: The different species of this family recorded were *Filinia terminalis*, *F. longiseta* and *F. opolensis*. Of these, *F. terminalis* occurred in March, April and May with a peak in March (87/m^3) at Station 2 and this species was absent at Station 1. *F. longiseta* was observed in August and October at Station 2 and *F. opolensis* in April only at Station 2. However, both of these species were not observed at Station 1, during the period of study.

Lepadellidae: *Lepadella ovalis* and *L. patella* were the two species recorded in the collection under this family but were absent at Station 1. At Station 2, *L. ovalis* was observed in November and December and *L. patella* was recorded in April and December.

Asplanchnidae: A*splanchna brightwelli* was the only species recorded from this family. The maximum population density of this taxon was observed during the pre-monsoon, especially in May at Station 1 and in April at Station 2. The abundance of this predatory rotifer showed a relative correlation with that of the species belonging to the genera *Brachionus* and *Keratella*.

Other rotifers: Among the other rotifers, *Polyarthra vulgaris* (Family: Synchaetidae) and *Hexarthra intermedia* (Family: Hexarthridae) occurred in abundance. *P. vulgaris* was observed during the pre-monsoon, monsoon and

post-monsoon periods at Stations 1 and 2 with a peak in March (478/m^3) at Station 1 and in April (194/m^3) at Station 2. *H. intermedia* recorded its maximum density during the pre-monsoon period at both stations. The rotifers *Epiphanes macrourus* (Family: Epiphanidae), *Dipleuchlanis propatula* (Family: Euchlanidae), *Testudinella patina* (Family: Testudinellidae) and *Trichotria tetractis* (Family: Trichotriidae), though present, were not common. *T. tetractis* and *D. propatula* were observed in September while *M. ventralis* (Mytilinidae) in November at Station 2. *T. patina* was observed during pre-monsoon at Station1 and during the pre-monsoon and post-monsoon seasons at Station 2.

Results of the correlation analysis between the dominant rotifer species and hydrography are given in Tables 3 and 4. Significant positive correlation was seen between *B. angularis* and surface water temperature ($p<0.01$) and total alkalinity ($p<0.05$) and a significant inverse relationship with nitrate ($p<0.05$) and silicate ($p<0.01$) at both the Stations. However, *B. angularis* exhibited significant positive relationship with pH ($p<0.01$), salinity ($p<0.05$) at Station 1 and no significance at Station 2. *B. calyciflorus* exhibited a significant positive relationship with water temperature ($p<0.05$), pH ($p<0.05$) and a significant negative relationship with silicate ($p<0.05$) at Station 1. However, at Station 2, it exhibited significant positive relationship with dissolved oxygen ($p<0.01$). *B. plicatilis* did not show any significant relationship with any of the hydrographic factors at Station 1, while at Station 2 it exhibited a significant positive relationship with water temperature ($p<0.01$) only. Likewise, *K. cochlearis* did not show any significant relationship with any of the hydrographic factors at both stations whereas *K. tropica* showed significant positive relationship with water temperature ($p<0.05$), salinity ($p<0.01$) and total alkalinity ($p<0.01$), and a significant inverse relationship with phosphate ($p<0.05$) and silicate ($p<0.01$) at both stations in the present investigation.

Species Diversity Indices

Monthly variations in the diversity index of the rotifers at the two Stations are given in Tables 5 and 6.

Diversity Index (H): The diversity index (H) values at Station 1 ranged from 0.14893 in July to 1.85638 in March, and from 0.43625 in December to 2.50054 in November at Station 2. When the index was seasonally examined it could be seen that the diversity index was the highest during the pre-monsoon period at both the stations and the lowest during the monsoon period.

Species Dominance (C): The dominance index (C) at Station 1 ranged from 0.35006 to 1.29034. Dominance index was found at its maximum at Station 1 in March due to the high dominance of *B. calyciflorus* (Table 1). At Station 2, the values varied from 0.10813 to 0.85399 with a peak in December due to the dominance of *K. cochlearis* (Table 2). Seasonal observations showed that at Station 1 maximum dominance was during the post-monsoon period followed by the monsoon period, whereas at Station 2, the maximum dominance was noticed during the pre-monsoon followed by monsoon, and the minimum during the post-monsoon period.

Species Richness (δ): The species richness index (δ) of rotifers at Station 1 ranged from 0.27279 to 2.07520 and from 0.96273 to 2.99363 at Station2. Seasonal analysis showed that at Stations 1 and 2, the maximum species richness was observed during the monsoon followed by the post-monsoon and the minimum during the pre-monsoon period.

Evenness Index (e): The Evenness index (e) of rotifers ranged from 0.13510 to 0.64226 at Station 1. At Station 2, it ranged from 0.16531 to 0.97185 registering the maximum in September. Seasonal observations showed that the evenness index was the maximum during pre-monsoon at Station 1 and during post-monsoon at Station 2.

Veli-Aakulam: A moderately saline Eutrophic Estuary

Monthly variations in selected hydrographical parameters at three stations in Veli-Aakulam estuary are given in Fig. 107a - l.

The water temperatures at Stations 1, 2 and 3 varied from 26.00°C (June and August) to 30.50°C (May) (Fig. 107a). Surface salinity fluctuated from 1.14 ppt (August) to 6.07 ppt (September) at Station 1, from 0.26 ppt (August) to 5.06 ppt (September) at Station 2 and from 0.12 ppt (March and May) to 1.24 ppt (January) at Station 3 (Fig. 107b). Maximum salinity values were noticed during the post-monsoon at Stations 1, 2 and 3. However, a gradual decrease of salinity during monsoon, followed by an increase in post-monsoon was noticed at Station 2. However, such wide fluctuations as in others were not observed at Station 3.

In all the three stations, considerable variations in pH were observed. It was the maximum (8.53) in the month of July at Station 1, in July at Stations 2 (8.41) and 3 (7.53) (Fig. 107c). However, the pH values were higher when algal blooms occurred. The total alkalinity concentrations ranged from 59.48 mg/l (August) to 79.32 mg/l (July) at Station 1, from 11.83 mg/l (August) to 98.33 mg/l (July) at Station 2 and from 37.06 mg/l (August) to 74.23 mg/l (January) at Station 3 (Fig. 107d). The total alkalinity concentrations were high at Station II when compared to those of the other stations.

Dissolved oxygen values recorded a peak in January (6.52 mg/l) at Station 1, in July (7.32 mg/l) at Station 2 and in January (5.72 mg/l) at Station 3 (Fig. 107e). The dissolved oxygen observed in the month of August was low at all the three stations.

The peak concentration of free-carbon dioxide occurred in August at Stations 1(42.83 mg/l), 2 (54.84 mg/l) and 3 (78.72 mg/l) (Fig. 107f). The level of free-carbon dioxide was high at all the three stations when pH and dissolved oxygen were low.

The concentration of nitrite-nitrogen was minimum in July and maximum in August at Station 1 (0.00 µg/l and 6.14 µg/l) and the same in September and August at Station 2 (0.11µg/l and 7.35 µg/l) and in July (0.73

µg/l) and August (8.35 µg/l) at Station 3 (Fig. 107g). The highest concentration of nitrate-nitrogen was observed in August at Stations 1 (17.82 µg/l) and 2 (20.83 µg/l) while it was in May (27.73 µg/l) at Station 3. The lowest concentration of nitrate was observed in the month of September at Stations 1 (0.44 µg/l) and 2 (1.24 µg/l) and in July (1.68 µg/l) at Station 3 (Fig. 107h).

Phosphate concentration varied from 0.14 µg/l (September) to 11.78 µg/l (August) at Station 1, from 0.34 µg/l (September) to 11.58 µg/l (August) at Station 2 and varied from 0.56 µg/l (July) to 13.04 µg/l (May) at Station 3 (Fig. 107i). Silicate concentration at Stations 1, 2 and 3 fluctuated from 4.94 µg/l (July) to 22.86 µg/l (September), 4.94 µg/l (July) to 25.86 µg/l (September) and from 5.92 µg/l (July) to 28.23 µg/l (May) respectively (Fig. 107j). Phosphate and silicate values were high during the monsoon and post-monsoon seasons at Stations 1 and 2, while those observed at Station 3 were relatively high throughout the period of study with no remarkable seasonal variations.

The concentrations of hydrogen sulphide and ammonia-nitrogen were high in the month of August at Station 1 (1.95 µg/l and 5.33 µg/l) and at Station 2 (1.25 µg/l & 8.83 µg/l). The concentration of hydrogen sulphide and ammonia-nitrogen at Station-3 were high in May (4.13 µg/l and 15.33 µg/l) (Fig. 107k &l).

Algal blooms: Regular blooms were characteristic feature of the Veli-Aakulam estuary. Blue-green algal blooms comprising *Microcystis aeruginosa* were recorded in May at Stations 1 and 2, whereas a mixed algal bloom of *Arthrospira, Microcystis aeruginosa* and *Sprulina* were noticed in July at all the three stations. A mixed diatom boom dominated by *Cyclotella* was observed in June and January at Stations 1 and 2, while the diatom *Chaetoceros* dominated the bloom observed in September at Stations 1 and 2. A bloom comprising *Cyclotella* was recorded in January at Station 3. The

blue-green algal blooms were generally observed during low saline periods, while the diatom blooms showed a direct relation with the increase in salinity and the silicate concentrations.

Rotifer Abundance and Species Composition

Monthly variations of rotifer abundance and species composition are given in Tables 7, 8 and 9. In Veli-Aakulam estuary, the population density observed was the highest in March at Stations 1 (52243/m^3) and 2 (83677/m^3) whereas it was in January at Station 3 (19409/m^3). The least densities were noted in August (431/m^3) at Station 1 and in May at Stations 2 (578/m^3) and 3 (25/m^3). A secondary peak was noticed in April (41438/m^3) at Station 1, in February at Station 2 (31363/m^3) and in March at Station 3 (13470/m^3). The results of the correlation analysis did not show a consistent relation between the total rotifer density and hydrographic factors at Stations 1 and 2, whereas the same showed a significant relationship with dissolved oxygen ($p<0.05$) and nitrate ($p<0.05$) at Station 3 (Tables 10-12).

A total of 31 species belonging to 16 genera and 12 families was recorded from these sites during the period of study. The family Brachionidae dominated the rotifer fauna, contributing 14 species, followed by Lecanidae (three species), Lepadellidae (three species), Filiniidae (three species) and Mytilinidae (two species). Families such as Epiphanidae, Asplanchnidae, Testudinellidae, Synchaetidae, Hexarthridae, Euchlanidae and Notommatidae were represented by only one species each.

Brachionidae: This family represented by three genera, namely *Brachionus*, *Keratella* and *Platyias*. Of these, the genus *Brachionus* formed the dominant component among the rotifers throughout the period of study at all the three Stations. The different species of family Brachionidae were *Brachionus angularis*, *B. budapestinensis*, *B. calyciflorus*, *B. falcatus*, *B. patulus*, *B. plicatilis*, *B. quadridentatus*, *B. murray*, *B. rotundiformis*, *B. rubens*

and *B. urceolaris* (Genus - *Brachionus*), *K. cochlearis*, *K. tropica* (Genus - *Keratella*), *Platyias quadricornis* and *P. leloupi* (Genus - *Platyias*).

Among the brachionid rotifers *B. angularis*, *B. plicatilis*, and *B. calyciflorus* were the most abundant in all the three stations. *B. angularis* occurred in all the seasons with peaks during pre-monsoon at Stations 1, 2 and 3, while minimum were observed during post-monsoon at Station 1 and during monsoon at Stations 2 and 3. The maximum population density of *B. plicatilis* was observed in January, followed by April, at Station 1, in March at Station 2 and in January at Station 3. Similarly, species such as *B. calyciflorus*, *B. budapestinensis*, *B. falcatus*, *B. patulus*, *B. quadridentatus*, *B. rubens* and *B. urceolaris* recorded their maximum population density during pre-monsoon followed by post-monsoon seasons. However, *B. murray* showed a distinct pattern of abundance during the period of study. The peak period of numerical abundance of this species was during monsoon, especially in the month of September, followed by post-monsoon, chiefly January at Stations 1 and 2, whereas at Station 3 this species were recorded in September and January with very low numerical abundance. *B. rotundiformis* was observed only in September at Station 1 and its population density was very low (5/m^3) during the period of study.

Others, especially the species belonging to the genera *Keratella* and *Platyias* showed a rather discontinuous occurrence in the sample collection during the period of study. Of these, *K. tropica* was observed in February, April, September, December and January at Station 1; in February, August, December and January at Station 2 and in March and April at Station 3. However, the other species, *K. cochlearis* was observed in August at Stations 1 and 2 eventhough it is a perennial species of Poonthura water. *Platyias quadricornis* was observed in March at Station 1, in October at Station 2 and in February, March, April and October at Station 3, whereas *P. leloupi* occurred in October at Station 3 only.

Lecanidae: The different species represented from this family were *Monostyla bulla*, *Lecane curvicornis* and *L. luna*. Of these, M. *bulla* was recorded at all the three stations, whereas *L. curvicornis* was recorded at Stations 2 and 3. *L. luna* was observed at Station 3 only. All the three species were not common during the period of study. The maximum occurrence of *M. bulla* was observed in March at Station 1, in October at Station 2 and in February at Station 3. However, the maximum population density of *L. curvicornis* and *L. luna* were observed during pre - monsoon period at Stations 2 and 3.

Lepadellidae: In the present study three species of *Lepadella* namely *L. crestata*, *L ovalis* and *L. patella* were observed under this family. Of these, *L. crestata* and *L. patella* were recorded at Station 1, and *L. crestata* alone at Station 2, while all the three species were noted at Station 3. All of them were not common in the present study.

Filiniidae: The members of this family were present at all the three stations in fairly conspicuous numbers. The different species of this family recorded were *Filinia terminalis*, *F. longiseta var. limnetica* and *F. cornuta*. Of these, *F. terminalis* and *F. longiseta* were the most abundant. The peak period of *F. terminalis* was in March at all the three Stations whereas the period of abundance of *F. longiseta* was in June at Station 1, in March at Station 2 and in April at Station 3. However, the peak period of *F. cornuta* was in January in all the three stations.

Mytilinidae: *Mytilina crassipes* and *M. ventralis* represented from this family and these rotifers were not common in the present study but were present only in the samples from Station 3. Of these, *M. crassipes* appeared only once, in the month of March, and the other, *M. ventralis* occurred in the months of April and September at this station.

Other Rotifers: Among the other rotifers, *Polyarthra vulgaris*, (Family: Synchaetidae), *Hexarthra intermedia* (Family: Hexarthridae) and *Asplanchna brightwelli* (Family: Asplanchnidae) were the most abundant. *P. vulgaris* had a peak population density in March at Stations 1 and 2 and in January at Station 3. The peak period of dominance of *H. intermedia* was in January at Station 1 and in October at Station 3, while that of *A. brightwelli* was in June at Station 1, March at Station 2 and January at Station 3. The rotifers such as *Dipleuchlanis propatula* (Family: Euchlanidae), *Epiphanes macrourus* (Family: Epiphanidae), *Testudinella patina* (Family: Testudinellidae) and *Scaridium longicaudum* (Family: Notommatidae) were present only in sparse numbers. *D. propatula* was observed in July and November at Station 3 alone during the present study, while *T. patina* was observed in April and August at Station 1, in August at Station 2 and in October at Station 3. The notommatid rotifer, *S. longicaudum* was observed in October at Station 1 and in May at Station 3, while *E. macrourus* was observed in May, October and November at Station 3 only.

The results of the correlation analysis between the dominant rotifers and hydrography at Stations 1, 2 and 3 are given in Tables 10, 11 and 12 respectively and these results revealed the following relationships. Among the individual rotifer population density, *B. angularis* did not show any significant relationship with any of the hydrographic factors at all the three stations except nitrate at Station 3. Similarly, *B. calyciflorus* showed significant negative relationship with nitrate ($p<0.05$) at Station 3. *B. plicatilis* exhibited significant positive relationship with salinity ($p<0.01$) and significant inverse relationship with nitrate ($p<0.05$) at Station 3. The haline rotifer *B. murray* showed significant positive relationship with salinity ($p<0.01$), pH ($p<0.05$), dissolved oxygen ($p<0.05$) and silicate ($p<0.05$) at Stations 1 and 2 in the present study.

Species Diversity Indices

Diversity Index (H): The species diversity index of rotifers at Stations 1, 2 and 3 are given in Tables 13, 14 and 15 respectively. The diversity index

of rotifers at Station 1 ranged from 0.33009 (September) to 1.59684 (March), at Station 2 from 0.53535 (December) to 1.63295 (April) and at Station 3 varied from 0.16479 (June) to 1.76757 (October).

Species Dominance (C): The dominance index of rotifers at Station 1 varied from 0.24750 (March) to 0.84278 (September), from 0.23777 (April) to 0.75794 (December) at Station 2 and varied from 0.23522 (May) to 0.97030 (March) at Station 3.

Species Richness (δ): The species richness index (δ) of rotifers at Station 1 varied between 0.59946 (September) and 1.31679 (April); between 0.71990 (December) and 1.57243 (May) at Station 2; between 0.30010 (August) and 2.17273 (April) at Station 3.

Evenness Index (e): The evenness index of rotifer varied from 0.15780 (November) to 0.61581 (July) at Station 1; from 0.27511 (December) to 0.70918 (April) at Station 2; from 0.10239 (June) to 0.85664 (May) at Station 3.

DISCUSSION

The short life-cycle and rapid reproduction of rotifers allow changes in community composition to track environmental shifts on the time scales that are not possible from the contemporary community data of longer-living organisms such as large zooplankton, fishes etc,. The total abundance of the rotifer community is the sum of the population development of the individual species, which is influenced by varying biotic and abiotic factors of the environment. Thus, the physico-chemical parameters determine the degree of pollution caused, and the changes in the trophic conditions can be reflected in the occurrence, pattern of distribution and diversity of rotifer community in their inhabited area (Irena, 1983; Archana, 1998).

In the present study the maximum temperature was observed during pre-monsoon, and the minimum during monsoon at all stations of Poonthura and Veli-Aakulam estuaries. The amplitude of temperature fluctuation was very narrow, only within a range of 0.7°C to 5.2°C during the period of study. A similar trend in surface water temperature has been reported by Suseela (1993) from Poonthura, and Asha (1990), Rani (1995) and Gopakumar (1998) from Veli. In general the temperature showed a positive relation with rotifer abundance at both estuaries since the maximum number of species and abundance were observed during the pre-monsoon in the present study. A similar trend in rotifer occurrence was reported by Suseela (1993) and Gopakumar (1998) from the same estuaries. However, temperature could not be taken as single limiting factor in determining the fluctuations in the rotifer species composition in these estuaries because this parameter itself has no direct influence on the community, but temperature influences other ecological parameters which in turn affect rotifer abundance and distribution (Galkovskaya, 1987). Bērziņš and Pejler (1989) studied the impact of temperature on rotifers and they grouped the rotifers into different categories depending on the tolerance capacity of rotifers and temperature variations and opined that rotifers namely *Keratella hiemalis*, *Kellicottia* sp. and *Notholca* sp. are 'cold stenothermal', and that other brachionids are warmwater species or 'eurythermal'. The same authors also suggested that most rotifers, especially the tropical fauna, have a very wide tolerance range of temperature, and the difference in temperature dependence exists among the rotifer species. Therefore the highest dominance of *Brachionus* species together with the complete absence of the above mentioned rotifers in the present study have revealed that warmwater or typical tropical rotifer fauna thrived in these estuaries. King and Serra (1998) have studied the influence of abiotic factors on the seasonal succession of three haline rotifers namely *B. plicatilis*, *B. rotundiformis* 'S' type and *B. rotundiformis* 'ss' type in Spain waters. According to their study the major environmental barriers in the co-existence of these rotifers, especially between *B. plicatilis* and *B. rotundiformis* were temperature (*B. plicatilis* ≤ 20°C; *B. rotundiformis* ≥ 20°C) and salinity. However, three

morphologically distinct rotifers, *B. plicatilis*, *B. murray* (*B. rotundiformis* 'S' type) and *B. rotundiformis* co-occurred during the period of this study at Veli-Aakulam estuary, and this observation has confirmed that temperature is not a limiting factor for the co-existence of these rotifers in tropical estuaries. A similar observation of *B. plicatilis* together with *B. rotundiformis* (= *B. plicatilis* 'S' type) was reported by Gopakumar (1998) from the same environment and other high saline estuaries of Kerala.

Among the hydrographical parameters studied, salinity was the most fluctuating parameter, with a wide range of variations. A marked gradient of decreasing salinity was evident from the barmouth to the upper reaches of the Veli-Aakulam and Poonthura estuaries, and this in conformity with the studies of Nair *et al.* (1984), Asha (1990), Bijoy Nandan (1991) and Suseela (1993) who reported a similar spatial distribution of salinity from the different estuaries of Kerala.

The maximum salinity observed in the present study was less than 10 ppt at both estuaries revealing that these estuaries are moderately saline. Therefore the correlation analysis between the rotifer abundance and salinity variations showed a positive relation revealing that the rotifer community in these estuaries was well adapted to the variations within their tolerable limits. Thus the present observation was in agreement with that of Gopakumar (1998) who reported that low-saline water bodies harboured a rich rotifer fauna than the high-saline water bodies. However, the individual rotifer species showed a rather distinct correlation with salinity variations during the period of study. Therefore the rotifers observed in the present study can be grouped into the following categories depending on their availability and salinity fluctuations: i) Oligohaline, the rotifers which are strictly freshwater inhabitants, but can tolerate a salinity upto 5 ppt; ii) Mesohaline, the rotifers which can tolerate a moderate salinity upto 15 ppt, and iii) Euryhaline, the rotifers which can tolerate a wide range of salinity, 0.5 ppt to ≤ 88 ppt (Ruttner-Kolisko, 1971; Dumont and de Ridder, 1987; Miracle *et al.*, 1987). Accordingly

the rotifers such as *Brachionus budapestinensis*, *B. caudatus*, *B. dichotomus reductus*, *B. kostei*, *B. patulus*, *B. urceolaris*, *B. quadridentatus*, *Filinia longiseta*, *F. terminalis*, *F. opolensis*, *Lecane curvicornis*, *L. leontina*, *L. ludwigi* and *Keratella cochlearis* observed within a salinity range of 0.18 ppt to 3.06 ppt are true freshwater forms but they could tolerate a low level of salinity. Rotifers such as *B. angularis*, *B. calyciflorus*, *K. tropica*, *Hexarthra intermedia*, *Polyarthra vulgaris* and *F. cornuta* observed at salinity range of 0.18 ppt to 5.07 ppt could tolerate a moderate level of salinity. Such moderate level of salinity tolerance of rotifers namely *Hexarthra* sp. *Polyarthra* sp. and *K. tropica* observed by the author is in agreement with that reported by de Ridder (1959, 1991) and Gopakumar (1998), while Aranovich and Spektorova (1974) opined that *B. calyciflorus* could tolerate a salinity range of 0.5 ppt to 10 ppt, Miracle *et al.* (1987) reported that *B. angularis* showed a wider tolerance range of 0.05 ppt to 24 ppt. However, in the present study *B. calyciflorus* showed a negative relationship with salinity and could not tolerate the range above 5 ppt. Similarly, *B. angularis* also recorded a reduced numerical abundance in higher salinity during the period of study. The abundance and occurrence of *B. angularis* throughout the year revealed that it could thrive well in oligo-mesohaline habitat but the tolerance range of salinity proposed by Miracle *et al.* (1987) is too wide to suggest their salinity sensitivity. The occurrence of *K. tropica* with a salinity range upto 16 ppt was reported by Gopakumar (1998) who agreed that this species could also inhabit the oligo-mesohaline habitat.

The rotifer *B. plicatilis* is the most tolerant of the *Brachionus* species, being found in both oligo-haline waters ranging from 0.12 ppt 10 ppt. However, Miracle *et al.* (1987) have reported this species from a salinity range of 0.5 ppt to 88 ppt from the Mediterranean wetlands of Spain. The correlation analysis between rotifer abundance and salinity revealed a significant positive correlation between them in the present study, and that was in conformity with the findings of Gopakumar (1998).

The numerical abundance of *B. murray* was high in Veli-Aakulam estuary at Station I with a salinity of above 5 ppt, indicating that this species preferred a higher saline condition. However, this species had very low density or it was totally absent at other stations of Veli-Aakulam and Poonthura estuaries where the salinity remained below 1 ppt. These observations revealed that *B. murray* could tolerate a low salinity but preferred a high salinity regime as observed by Gopakumar (1998) and Haberman and Sudzuki (1998) who reported that *B. rotundiformis* was more numerous near the mouth of estuary where the salinity was higher. However, Carmona *et al.* (1995) had reported this species from Spain in salinity ranging from 5 ppt to 64 ppt, whereas accordingly to Virro (1993), Virro and Haberman (1993), *B. rotundiformis* was abundant at salinity upto 3.9 ppt. Similarly, Haberman and Sudzuki (1998) and King and Serra (1998) have studied the importance of salinity and temperature conditions and according to them these two factors significantly influenced the occurrence and abundance of this taxon in their natural habitats. Results of the correlation analysis revealed that this taxon exhibited significant positive relationship with salinity similar to the findings of Haberman and Sudzuki (1998) and Gopakumar (1998).

Another haline rotifer *B. rotundiformis* was observed in September at Veli-Aakulam, Station 1 at salinity of 6 ppt when there was a marked increase in the diatoms. This population showed a close similarity to *B. rotundiformis* in morphology with lorica length ranging from 125 μm to 145 μm. The numerical representation of this population was 5/m^3 and was not observed in any other station or season during the period of study. The morphology and ecology of this taxon were studied by Serra and Miracle (1987), Hagiwara *et al.* (1995) and Serra *et al.* (1998). According to them this rotifer is the original Tschugunoff's *rotundiformis*, which generally showed a close affinity to high salinity and temperature. Small-sized rotifers with a mean lorica length ranging from 130 μm to 140 μm have been reported from Dalavapuram (high saline estuary) of *B. plicatilis* Gopakumar (1998) and this might be *B. rotundiformis*. Thus, the present study shows that salinity plays a crucial role in the

occurrence, distribution and dominance of rotifer community in these estuaries, if other variables are not limiting. Such a view was expressed by Kinne (1963, 1964), Nair *et al.* (1984), Nair and Abdul Aziz (1987) and Gopakumar (1998). According to them, salinity is the most important variable affecting the distribution of plankton in estuaries and the backwaters of Kerala.

The seasonal variation in pH was high during the pre-monsoon and low during the monsoon. The high pH during the pre-monsoon was due to higher photosynthetic rates. The decrease in pH towards the acidic side or near neutral at all the stations during monsoon could be attributed to heavy river discharge and land run-off. Asha (1990) and Suseela (1993) were also observed a similar pattern of pH from these estuaries and this is in agreement with the present study. Regarding the influence of pH on rotifer abundance, different workers had expressed different views. Berzinš and Pejler (1987) considered rotifers as pH insensitive but Arora (1966) on the contrary has experimentally proved that most rotifers are sensitive to pH fluctuations (5.5 to 12.6). In the present study the recorded range of pH was about 5.1 to 7.42 at Poonthura estuary and at Veli-Aakulam estuary it ranged from 5.42 to 8.53. The least number of rotifers together with low levels of pH was observed at both the estuaries, suggesting that the rotifers are sensitive to low pH. Arora (1966) also observed the same phenomenon. The rotifers such as *B. angularis* and *B. plicatilis* were observed at Veli-Aakulam within a pH range of 5.42 to 8.53; while *B. angularis*, *B. plicatilis* and *K. cochlearis* at Poonthura within a pH range of 5.1 to 7.42 revealing that these rotifers could tolerate a wide range of pH fluctuations than other rotifers. Thus the present observations are in conformity with those of Koste and Shiel (1983), Shiel and Koste (1986), Brett (1989), Leitão *et al.* (1992) and Anuradha Rammohan (1996) who had reported *B. angularis*, *K. cochlearis* and *B. plicatilis* from waters with low pH. However, the low population density of these rotifers in waters of low pH suggests that these rotifers can survive in waters with low pH but their population growth is much reduced. However, pH could not be taken as a limiting factor in determining the availability and abundance of species

encountered during the current study because pH is an expression of other important chemical parameters especially salinity, total alkalinity and dissolved oxygen. It was more evident in the present study that comparatively low rotifer concentration and species diversity were observed in May at Stations I and II of Veli-Aakulam estuary eventhough these Stations recorded a high pH of 8.52 and 8.30.

The dissolved oxygen of surface waters greatly depends on primary production, water movements and wind-surface interaction. Unlike seawater, the wind-surface interaction and water currents are low in estuaries and freshwater bodies. A high level of dissolved oxygen observed during the pre-monsoon and the post-monsoon with notable concentrations of phytoplankton revealed that phytoplankton was the prime supplier of dissolved oxygen in these two estuaries. However, the difference in dissolved oxygen concentrations between Veli-Aakulam and Poonthura estuaries was due to the difference in the abundance of phytoplankton, hence the rate of photosynthesis in these estuaries. Veli-Aakulam estuary was subjected to different algal blooms and such distinct blooms were not observed in Poonthura, and that might be one of the reasons for the drastic difference in dissolved oxygen between these two estuaries. Rani (1995) was also reported a high dissolved oxygen concentration with algal blooms from Veli estuary and this was in conformity with the present study.

Depending on the oxygen tolerance, rotifers are grouped into two categories, namely anoxic and oxic. Generally rotifers found in bottom waters are considered as anoxic, because of their ability to survive in low oxygen concentration, while planktonic rotifers are grouped as oxic, since their distribution is mainly in the surface layer where the oxygen content is high due to optimum primary production. However, such demarcations are not applicable to rotifer community in shallow water bodies where the stratification of oxygen from surface to bottom waters is nil or negligible. Therefore, the existence of anoxic conditions in surface waters is mainly due to aquatic

macrophytes decomposition or sewage discharge from the periphery of the estuaries. The surface water with low dissolved oxygen levels during the monsoon season was reported by Asha (1990), Rani (1995) and Gopakumar (1998) from different brackish water bodies of Kerala, and Anuradha Rammohan (1996) had reported low dissolved oxygen levels from Kadinamkulam Lake due to organic pollution (coconut husk retting area). Considering the relationship between the hydrographic factors and zooplankton density, oxygen was significantly correlated with total rotifer density in both the estuaries. The present observations are similar to the findings of Vasisht and Sharma (1976), Nayar (1970) and Jyoti and Sehgal (1979) that maximum species density was recorded in waters with high levels of dissolved oxygen. However, rotifers such as *B. angularis*, *B. plicatilis* and *K. cochlearis* were observed throughout the study period irrespective of dissolved oxygen variations which revealed that these species could tolerate a wide range of such variations than the other planktonic rotifers.

Low levels of free-carbon dioxide during the pre-monsoon and comparatively high levels during the monsoon were observed in the present study. The low levels or complete absence of free-carbon dioxide may be attributed to its complete consumption during photosynthesis. A similar trend was reported by Saha and Pandit (1986) and Amita and Saksena (1992) from freshwater habitats. An inverse relationship of free-carbon dioxide with dissolved oxygen and total alkalinity was suggested by Kant and Raina (1970) and Jyoti and Sehgal (1979) from different freshwater bodies and a similar relationship were observed in the present study.

The parameters such as free-carbon dioxide, hydrogen sulphide and ammonia were negatively correlated with rotifer population density. A low population density and low species diversity with high levels of these variables were observed in both the estuaries and this may be due to the constant exposure of Veli-Aakulam and Poonthura estuaries to sewage fed waters from Kannanmoola canal and Parvathy-Puthanar canal respectively during

monsoon period. However, the rotifers such as *B. angularis*, *B. plicatilis*, *M. bulla*, *F. longiseta*, *P. vulgaris* and *K. cochlearis* were observed in organically polluted waters with high levels of hydrogen sulphide, ammonia, free-carbon dioxide together with low levels of pH, dissolved oxygen and total alkalinity, and the present observations revealed that these rotifers could survive in polluted waters but their population growth was reduced at higher levels of these variables. A similar observation was made by Edmondson (1944), Arora (1966), Michael (1985) and Archana (1998) and they stated that the above species are good indicators of water with organic pollution. However, B. *plicatilis* showed an increased level of tolerance towards high levels of hydrogen sulphide than the other rotifers and the present observation substantiated the finding of Anuradha Rammohan (1996) who reported B. *plicatilis* from Kadinamkulam Lake that was constantly exposed to sulphide pollution due to retting of coconut husk.

An increase in phosphate, silicate, nitrite and nitrate concentrations was observed during monsoon and this was due to the heavy land run-off, river discharge and sewage pollution from the river into the estuary. This substantiated the significant negative correlations derived between the rotifer population density and nutrients. A Similar observation was reported by Bijoy Nandan (1991), Rani (1995) and Gopakumar (1998) from different estuaries of Kerala. However, individual species especially *B. angularis*, *B. plicatilis* and *K. cochlearis* showed non-significant correlation with nutrients, revealing that these rotifers could tolerate higher levels of nutrients than the other rotifers. A wide range of tolerance capacity of these rotifers on such variables may be one of the reasons for their representation in the samples throughout the study period irrespective of seasons. Amita and Saksena (1992) reported that high levels of nitrite-nitrate indicate high organic pollution. In the present study also high levels of nitrite and nitrate during monsoon indicated organic pollution. Leitão (1992) and Gopakumar (1998) have observed a negative relationship between the total rotifer abundance and nutrients from different estuarine environments and similar correlations were observed in the present

between the algal groups for limited nutrients available in their habitat. Furthermore, comparatively high quantity of *B. calyciflorus* was observed during the period of *Microcystis aeruginosa* bloom in the present study a phenomenon similar to the same reported by Starkweather and Kellar (1983). According to them *B. calyciflorus* consumes non-colonial forms of *Microcystis aeruginosa* but its survival and population growth are negatively affected by high concentrations of this alga.

Distinct diatom blooms were also observed in Veli-Aakulam during the period of study. The dominating taxa were *Chaetoceros* spp. and *Cyclotella* sp. The *Chaetoceros* spp. dominated bloom was observed in September at Station 1 and 2, whereas *Cyclotella* sp. bloom was observed in January at all the three stations. A mixed bloom dominated by *Cyclotella* sp. was observed in June at Station 1. Abundance of rotifers together with the diatom blooms showed the positive influence of these algal species on rotifer community in Veli-Aakulam estuary. Among the rotifers, *B. murray* showed its maximum population density when the *Chaetoceros* bloom was recorded, followed by *Cyclotella* bloom, whereas *B. calyciflorus* and B. *angularis* showed a reverse trend. However, *B. plicatilis* maintained an almost constant concentration in all the three stations irrespective of diatom blooms and salinity. Thus the present observation has suggested that diatoms play a crucial role on the density of different rotifers especially the haline rotifers *B. murray* and *B. rotundiformis* by serving as a potential food source. The lower population density of this taxon at Poonthura estuary than at Veli-Aakulam estuary may be due to the complete absence of a suitable food resource. Though significant positive correlation between B. *rotundiformis* (= *B. plicatilis* 'S' type, Veli strain) density and salinity was reported by Gopakumar (1998), but he has not recorded any blooms during his study. Accordingly the present study has confirmed the findings of Haberman and Sudzuki (1998) who reported *B. rotundiformis* from Lake Palaeostomi with a salinity range of 2.7 ppt to 6.6 ppt and good number of algal species especially *Cyclotella atomus*, *Ankistrodesmus* sp and *Scenedesmus* sp. Ian *et al.* (1998) opined that abundance of *K. cochlearis* is

correlated to the abundance of heterotrophic nanoflagellates or detritus. In the present study, *K. cochlearis* was observed throughout with a peak in December and January at Poonthura but the low occurrence of this species in Veli-Aakulam suggests that the primary limiting factors for the occurrence and abundance of this species might be lack of a suitable food resource and competition from other organisms. Thus, because of the low productivity in Poonthura estuary is generally considered as oligo-trophic and *K. cochlearis* is well adapted with this habitat due to its herbivorous-detritivorous filter feeding habits and less competition from other brachionids. The highest numerical abundance of this rotifer in December and January with high pH and comparatively high dissolved oxygen levels has suggested the dominance of heterotrophic nanoflagellates or colourless algae and that may be the reason for the dominance of *K. cochlearis* and the present observation had substantiated the findings of Gliwicz (1969) who reported the richness of *K. cochlearis* indicated a oligo-meso-trophic condition.

The changes in community structure can be explained numerically with diversity indices. These indices are useful in assessing water quality based on the principle that clean water supports high community diversity and polluted water has less diversified biota (Odum, 1971). The maximum value on Shannon-diversity index (H) was observed during pre-monsoon at all the stations of Veli-Aakulam and Poonthura estuaries in the present study. Similarly, the lowest values on diversity index were observed during monsoon season in these estuaries. However, diversity index is itself a function of species richness. Therefore species richness is a good indication of diversification of rotifers in these estuaries. The rotifer composition in Veli-Aakulam with 31 species and in Poonthura with 36 species revealed a significant correlation between diversity index and species richness in these estuaries. However, higher value of diversity index together with greater species richness was observed in Poonthura than in Veli-Aakulam estuaries, and this showed that, Poonthura estuary harboured more diversified rotifer fauna than Veli-Aakulam estuary.

The lowest values of diversity index, species richness and evenness index were recorded during the monsoon season in both the estuaries. These low values can be attributed to the water quality that occurred in these estuaries during the monsoon period. In the monsoon season, estuaries of Kerala were exposed to a number of changes such as heavy river discharge, land run-off, mixing of seawater and freshwater and organic pollution and have become highly dynamic and sensitive. As a result of these changes an entirely different water quality existed in estuaries during the monsoon period. Therefore, the low diversity index and species richness was found to inversely respond to these changes. A similar trend in species diversity, species richness and water quality has been reported by Trivedi (1981), Leitão *et al.* (1992) and Archana (1998) from various polluted water bodies.

The index of dominance (C) signifies the degree to which dominance concentrates in one species or group and this dominant group in a community may exert a powerful control over the other groups. The index of dominance would be always higher when a few groups dominate the community and it would be lower when the dominance is shared by a large number of species (Whittaker, 1965). The index of dominance is generally related to a low value on diversity index, species richness and evenness index. In the present study the maximum index of dominance was observed during post-monsoon at Station 1 and during the pre-monsoon at Stations 2 and 3 in Veli-Aakulam estuary while in Poonthura estuary the maximum values were observed during the post-monsoon at Stations 1 and 2. The dominant genera in Veli-Aakulam were *Brachionus*, *Filinia*, *Lepadella*, *Hexarthra* and *Polyarthra* and in Poonthura, the dominant genera were *Brachionus*, *Keratella*, *Lecane*, *Platyias*, *Filinia* and *Monostyla*. Pennak (1957) has pointed out that when more genera / species of the same group occur in any water body, one genus / species is more abundant than the others. In the present study *Brachionus* occurred as the most abundant genus with 10 species in Veli-Aakulam and 13 species in Poonthura. Green (1972), Saksena *et al.* (1986), Mishra and Saksena (1990), Govindasamy and Kannan (1991), Srivastava and Singh

(1995) and Gopakumar (1998) had earlier reported the abundance of this genus from various water bodies.

Every species is a product of the conditions under which it grows. Dominant species surviving in an ecosystem are significant indicators as they receive full impact of their habitats for longer period. Therefore zooplankters, particularly rotifers, are universally accepted as fairly reliable indicators of trophic status of aquatic ecosystem (Arora, 1966; Sampath *et al.*, 1979; Saksena, 1987; Chandrasekhar, 1998). Among the rotifers, *B. falcatus*, *B. forficula*, *B. quadridentatus* and *F. opolensis* are indicator species for clear water or oligo-trophic condition; those such as *B. angularis*, *B. calyciflorus*, *K. tropica*, *F. longiseta*, *F. terminalis* and *Polyarthra* sp. are indicator species of eutrophic or organically polluted waters according to Arora (1966) and Chandrasekhar (1998). Similarly, *B. caudatus personatus*, *Mytilina* sp., *Lecane leontina, L. ludwigi*, *Trichotria tetractis* and *K. cochlearis* are indicators of meso-eutrophic condition (Kaushik and Saksena, 1995). Therefore, the occurrence of *L. ludwigi*, *F. opolensis*, *B. falcatus*, *B. quadridentatus*, *T. tetractis*, *B. caudatus* and *K. cochlearis* in Poonthura estuary indicated the oligo-meso-eutrophic nature of water, whereas the highest dominance of *B. angularis*, *B. calyciflorus*, *B. plicatilis*, *B. budapestinensis*, *F. longiseta* and *F. terminalis* in Veli-Aakulam estuary revealed its meso-eutrophic condition. Thus the present study is in conformity with the findings of the workers cited above. However, Warren (1971) suggested that the continued persistence of a species at a particular location is sure evidence of favorable environment for its existence, but its absence is not always indicative of unfavorable conditions. This is true in the present study that the rotifers such as *K. tropica* and *B. caudatus* were poorly represented in the Veli-Aakulam plankton samples but these two species were reported by Gopakumar (1998) from the same environment throughout his study period.

From the forgoing, it is evident that there are differences in community structure and seasonal distribution of rotifers at the Veli-Aakulam and

Poonthura estuaries and this could be attributed to temporal changes in the ecological parameters and trophic status of these two estuaries. It is also clear from the present study that the rotifer community shows variations in the total number of species and their abundance in different months. Therefore, the rotifer succession in an ecosystem can be explained by physical and chemical limitations, food availability and other mechanical interference. All these parameters act in a combined manner and hence a single factor cannot be isolated for interpreting its relation with the community structure of rotifers. Among the studied variables, salinity and potential food resources showed a direct correlation on rotifer assemblage in the present study while other variables did not show any significant influence. Based on these observations, the experimental studies of certain brachionids were carried out in the laboratory and the results of these studies are presented in the following chapters.

Fig. 106a-m: Annual variations in rainfall and selected hydrographic parameters at two stations in Poonthura estuary during Feb. 2000- Jan. 2001

Fig. 106a

Fig. 106b

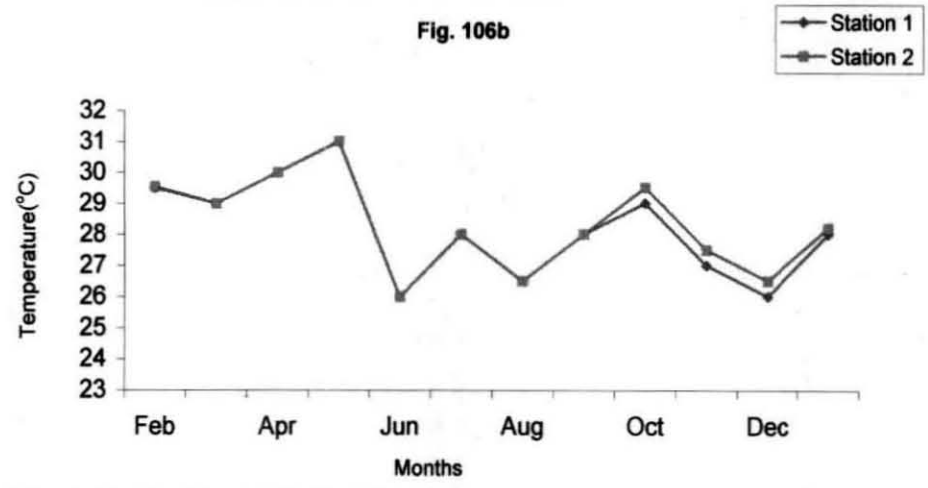
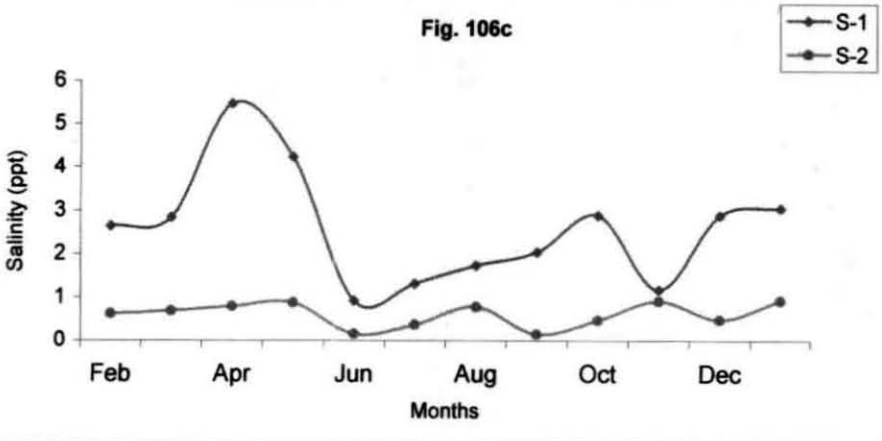


Fig. 106c



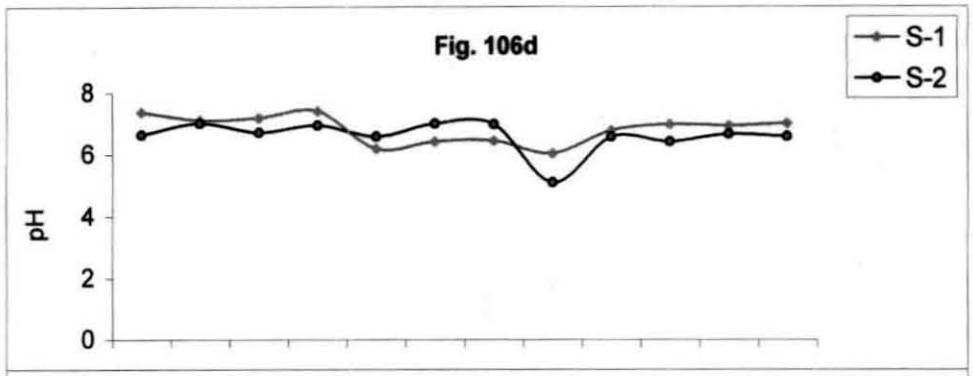


Fig. 106d
S-1
S-2
pH
8
6
4
2
0

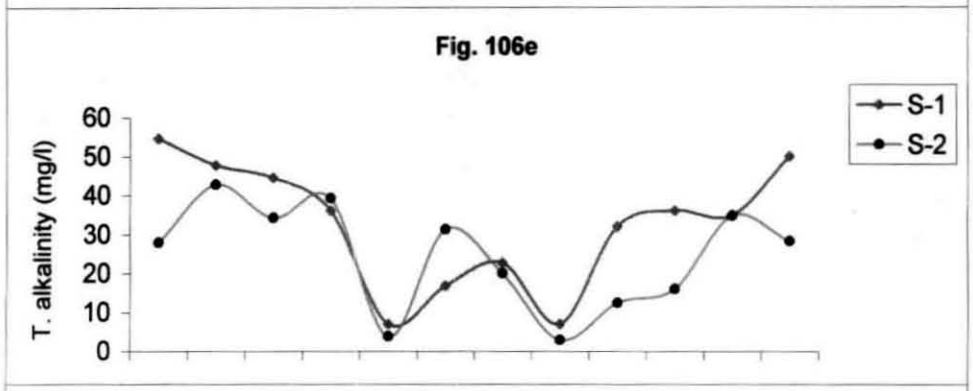


Fig. 106e
S-1
S-2
T. alkalinity (mg/l)
60
50
40
30
20
10
0

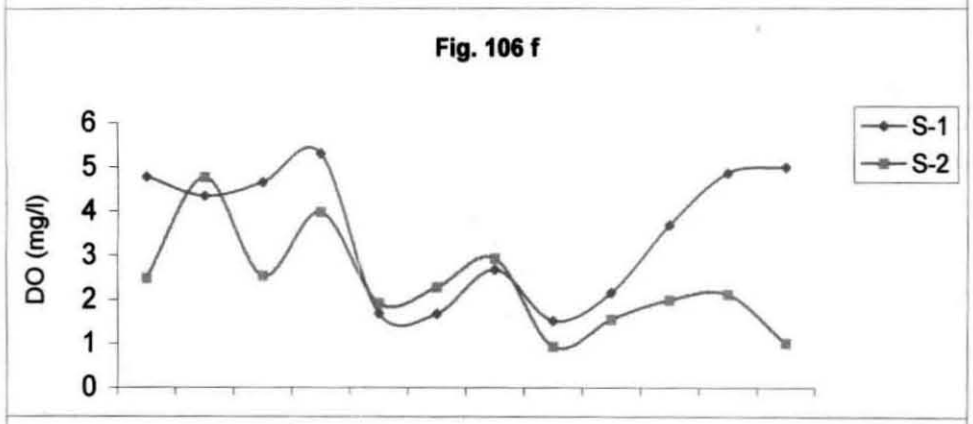


Fig. 106 f
S-1
S-2
DO (mg/l)
6
5
4
3
2
1
0

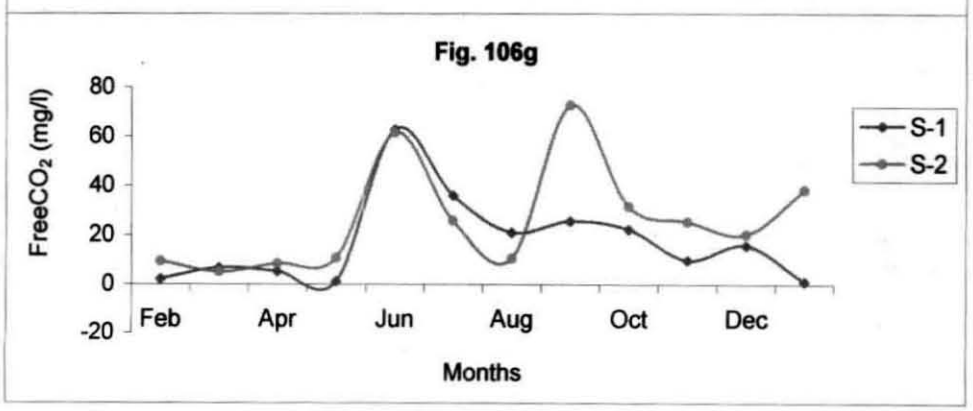


Fig. 106g
S-1
S-2
FreeCO2 (mg/l)
80
60
40
20
0
-20
Feb
Apr
Jun
Aug
Oct
Dec
Months

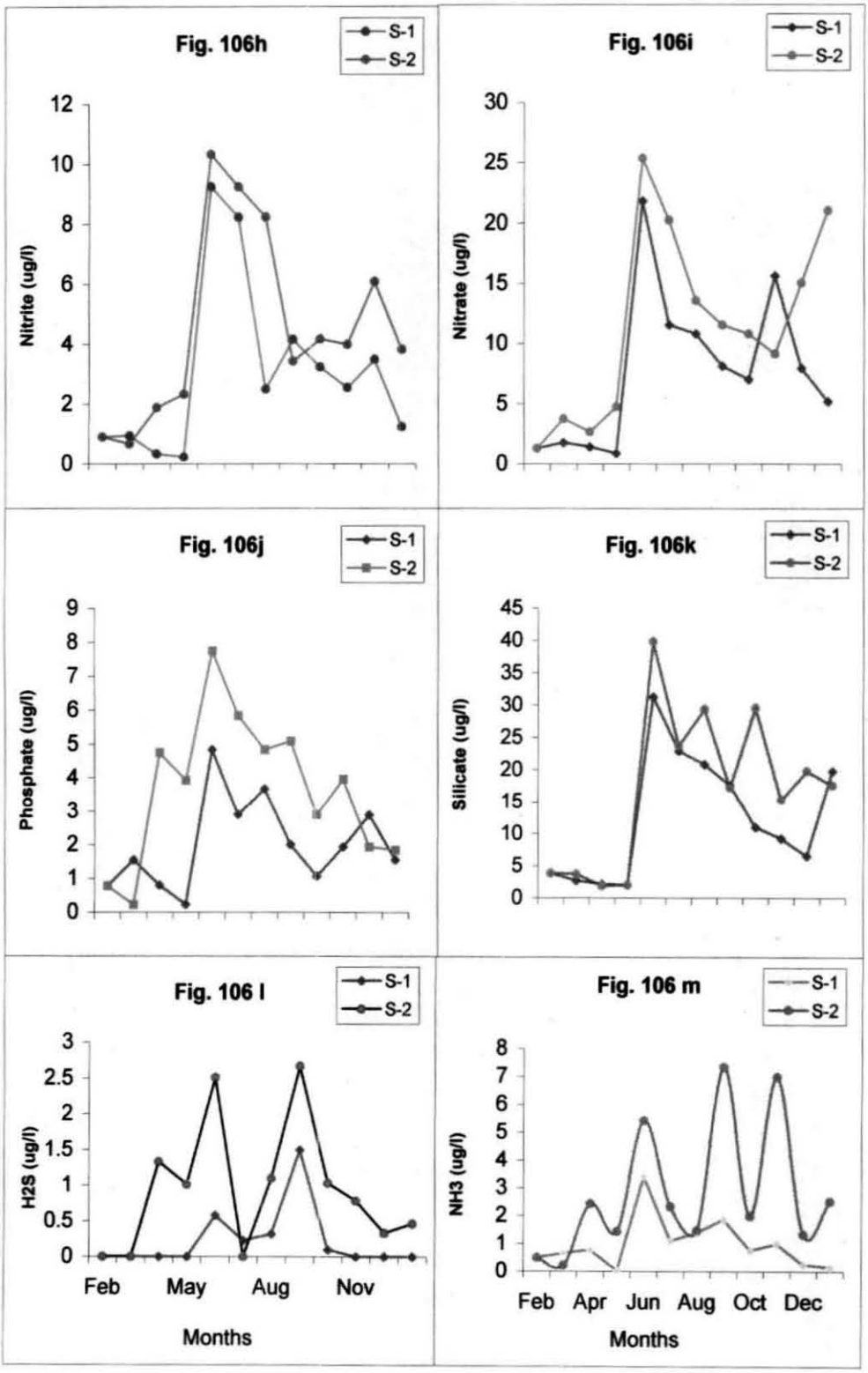


Fig. 106h
S-1
S-2
Nitrite (ug/l)
12
10
8
6
4
2
0
Fig. 106i
S-1
S-2
Nitrate (ug/l)
30
25
20
15
10
5
0
Fig. 106j
S-1
S-2
Phosphate (ug/l)
9
8
7
6
5
4
3
2
1
0
Fig. 106k
S-1
S-2
Silicate (ug/l)
45
40
35
30
25
20
15
10
5
0
Fig. 106 l
S-1
S-2
H2S (ug/l)
3
2.5
2
1.5
1
0.5
0
Feb
May
Aug
Nov
Months
Fig. 106 m
S-1
S-2
NH3 (ug/l)
8
7
6
5
4
3
2
1
0
Feb
Apr
Jun
Aug
Oct
Dec
Months

Table 1 Monthly average of rotifers (No/m^3) at Poonthura estuary- Station I

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Brachionus angularis	10649	458	13642	7530	34	35	52	9	15	28	100	10
B. calyciflorus	2150	6375	442	3560	-	-	-	-	-	-	-	16
B. caudatus	522	60	13	21	-	-	-	-	-	-	-	-
B. dichotomus reductus	4	48	-	-	-	-	-	-	-	-	-	4
B. falcatus	215	125	40	87	-	-	-	-	-	-	-	-
B. plicatilis	35	363	1306	269	7	1483	250	4	141	82	361	29
B. havanaensis trahea	1	1	-	2	-	-	-	-	-	-	-	-
B. quadridentatus	3	435	5	87	-	-	-	-	-	-	-	-
B. murray	-	2	7	3	-	-	-	-	-	-	-	2
B.rubens	-	2	-	4	-	-	-	-	-	-	-	-
B.urceolaris	532	5	348	179	-	-	-	-	-	-	37	-
Keratella cochlearis	4	4	2	2	239	10	12	52	351	215	162	800
K .tropica	209	654	828	144	-	-	-	-	-	-	-	2
Monostyla bulla	87	15	-	179	4	-	-	8	-	5	10	4
M. quadridentata	2	-	-	-	-	-	-	-	-	-	-	-
Lecane curvicornis	3	10	-	-	-	-	-	-	3	-	-	-
Asplanchna brightwelli	307	152	261	327	-	-	-	-	4	-	10	9
Polyarthra vulgaris	18	478	95	45	-	-	-	-	8	3	12	3
Hexarthra intermedia	31	586	435	1612	-	-	5	-	21	7	-	2
Testudinella patina	49	85	3	7	-	-	-	-	-	-	-	-
Total rotifers	14821	9858	17427	14058	284	1528	319	73	543	340	692	881
Algal blooms	--	--	--	--	--	--	--	--	--	--	--	--

Table 2a : Monthly average of rotifers (No / m^3) at Poonthura estuary- Station II

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Epiphanes macrourus	-	-	-	-	-	-	-	-	5	12	-	-
Brachionus angularis	76	337	15	621	2	15	56	2	5	5	5	27
B.calyciflorus	19	3733	21	65	-	-	-	-	-	-	4	28
B. caudatus	40	21	48	129	-	-	-	-	-	-	-	-
B. dichotomus reductus	4	3	18	52	-	6	-	-	-	-	-	-
B. falcatus	-	14	22	111	-	-	-	-	-	-	-	-
B. havanaensis trahea	1	1	-	-	-	-	-	-	-	-	-	-
B. kostei	1	-	-	-	-	-	-	-	-	-	-	-
B. patulus	-	-	-	-	-	-	7	-	-	-	-	-
B. plicatilis	8	55	80	400	4	42	84	2	25	28	8	5
B. pseudoforficula	2	-	-	-	-	-	-	-	-	-	-	-
B. quadridentatus	5	20	-	15	-	-	12	-	-	-	-	-
B. rubens	5	-	-	-	-	30	21	-	-	-	-	-
B.urceolaris	83	21	15	8	-	15	7	-	-	15	3	-
Keratella cochlearis	12	220	173	194	4	15	13	18	25	13	1269	1281
K. tropica	33	23	50	30	-	-	-	-	10	25	-	17

(Continued...)

Table 2b: Monthly average of rotifers (No / m^3) at Poonthura estuary- Station II (Continuation)

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Platyias quadricornis	-	-	-	-	-	-	7	-	-	-	-	-
P. leloupi	-	-	-	-	-	-	7	-	-	-	-	-
Monostyla bulla	25	35	12	22	3	30	70	-	15	15	37	-
M. quadridentata	-	35	-	-	-	-	-	-	-	3	5	-
Lecane curvicornis	2	-	5	-	-	-	35	-	-	-	-	-
L. luna	-	-	-	-	-	-	-	-	-	-	5	-
L. leontina	-	4	-	-	-	-	7	-	-	4	-	-
L. ludwigi	2	-	-	-	-	-	-	-	-	2	-	-
Lepadella ovalis				-	-	-	-	-	-	10	-	-
L. patella	-	-	-							-	3	-
Mytilina ventralis	-	-	5	-	-	-	-	-	-			
Trichotria tetractis	-	-	-	-	-	-	-	-	-	3	-	-
Asplanchna brightwelli	-	-	-	-	-	-	-	4	-	-	-	-
Polyarthra vulgaris	5	20	20	12	-	-	2	-	2	8	15	28
Dipleuchlanis propatula	5	59	194	8	-	15	14	-	4	3	7	7
Filinia terminalis	-	-	-	-	-	-	-	2	-	-	-	-
F. opolensis	-	87	7	8	-	-	-	-	-	-	-	-
F .longiseta	-	-	2	-	-	-	-	-	-	-	-	-
Hexarthra intermedia	-	-	-	-	-	-	7	-	5	-	-	-
Testudinella patina	25	653	129	75	-	5	3	-	-	3	5	45
	2	46	-	-	-	-	14	5	2	-	3	-
Total rotifers	353	5387	816	1750	13	173	366	33	98	149	1369	1438
Algal blooms	-	-	-	-	-	-	-	-	-	-	-	-

Table 3: Correlation coefficient of dominant and total rotifers with selected physico-chemical parameters of water at Poonthura estuary- Station I

Hydrographic Parameters	*Brachionus angularis*	*Brachionus calyciflorus*	*Brachionus plicatilis*	*Keratella cochlearis*	*Keratella tropica*	Total rotifers
Water temp. (°C)	0.681**	0.509	0.220	-0.202	0.503*	0.781**
Salinity (ppt)	0.728**	0.303	0.299	-0.073	0.669**	0.728**
pH	0.628**	0.526*	-0.013	0.180	0.490	0.735**
T. alkalinity(mg/l)	0.497	0.458	-0.040	0.110	0.499	0.599*
D. oxygen(mg/l)	0.522*	0.438	0.027	-0.041	0.438	0.611**
Free CO_2 (mg/l)	-0.466	-0.411	0.145	0.007	-0.401	-0.551*
Nitrite(µg/l)	-0.517*	-0.555*	-0.160	0.163	-0.494	-0.657**
Nitrate(µg/l)	-0.602**	-0.421	-0.051	0.029	-0.228	-0.628**
Phosphate(µg/l)	-0.593*	-0.566*	-0.091	0.337	-0.436	-0.663**
Silicate(µg/l)	0.596*	-0.299	-0.228	-0.142	-0.596*	-0.719**
Ammonia(µg/l)	-0.257	-0.255	-0.209	0.046	-0.228	0.077
H_2S(µg/l)	-0.316	-0.299	-0.210	-0.014	-0.311	-0.405

All the statistically significant values are marked with *: * $p<0.05$; ** $p<0.01$

Table 4: Correlation coefficient of dominant and total rotifers with selected physico-chemical parameters of water at Poonthura estuary- Station 2

Hydrographic Parameters	*Brachionus angularis*	*Brachionus calyciflorus*	*Brachionus plicatilis*	*Keratella cochlearis*	*Keratella tropica*	Total rotifers
Water temp. (°C)	0.672	0.184	0.650**	-0.219	0.724**	0.391
Salinity (ppt)	0.363	0.099	0.406	0.239	0.627**	0.363
pH	0.354	0.258	0.335	0.079	0.225	0.365
T. alkalinity(mg/l)	0.770**	0.443	0.437	0.368	0.489	0.675**
D. oxygen(mg/l)	-0.438	0.684**	0.577*	-0.212	0.361	0.732**
Free CO_2 (mg/l)	-0.437	-0.276	-0.328	-0.054	-0.801*	-0.401
Nitrite(µg/l)	-0.458	-0.365	-0.373	-0.029	-0.558*	-0.485
Nitrate(µg/l)	-0.190	-0.373	0.044	0.288	-0.751**	-0.359
Phosphate(µg/l)	-0.560*	-0.449	-0.430	-0.395	-0.590*	-0.576*
Silicate(µg/l)	0.355	-0.361	0.286	-0.063	-0.796**	-0.515*
Ammonia(µg/l)	-0.353	-0.309	-0.272	-0.299	0.024	-0.440
H_2S(µg/l)	-0.356	-0.308	-0.286	-0.401	-0.466	-0.458

All the statistically significant values are marked with *: * $p<0.05$; ** $p<0.01$

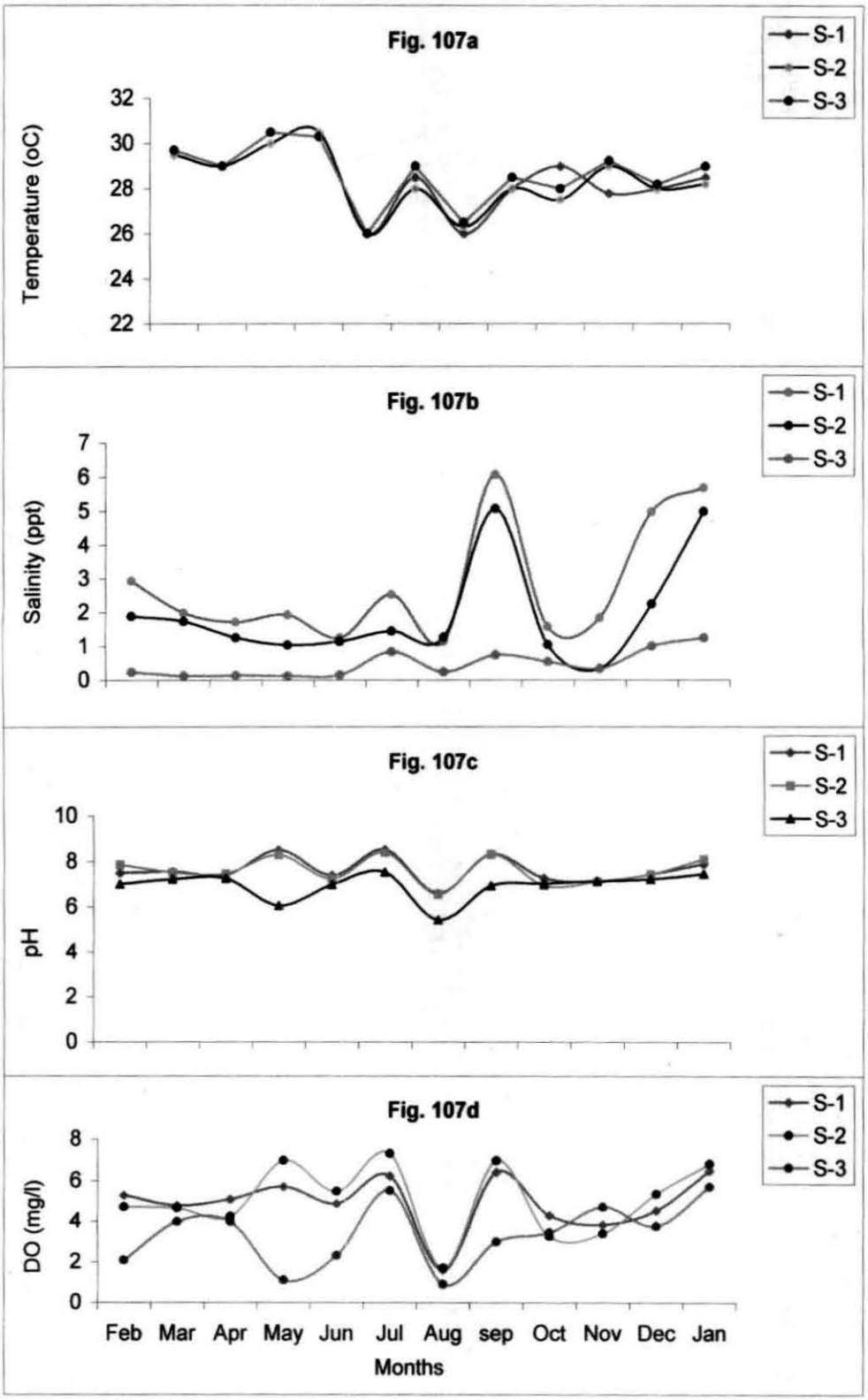
Table 5: Monthly and seasonal species diversity of indices rotifers at Poonthura estuary - Station I

Months/season	Shannon index	Dominance index	Species richness	Evenness index
February	0.73338	0.70072	2.07520	0.23726
March	1.85638	1.29034	1.96825	0.64226
April	1.02624	0.60077	1.53329	0.37014
May	1.15596	0.45820	1.40722	0.42686
Jun	0.55060	0.72334	0.53107	0.39718
July	0.14893	0.94253	0.27279	0.13510
August	0.47652	0.79035	0.53174	0.34374
September	1.17061	0.77488	0.89767	0.32025
October	1.08774	0.53704	1.32752	0.52309
November	0.75839	0.68494	1.14009	0.36471
December	1.31679	0.35005	1.07017	0.63324
January	0.70495	0.72152	1.15563	0.29399
Pre-monsoon	1.28295	0.29311	0.26922	0.92545
Monsoon	0.91091	0.52477	0.39017	0.67080
Post-monsoon	0.96697	0.66922	0.33840	0.48791

Table 6: Monthly and seasonal species diversity indices of rotifers at Poonthura estuary – Station 2

Months / seasons	Shannon index	Dominance index	Species richness	Evenness index
February	2.43360	0.17551	2.95683	0.84188
March	1.24332	0.70473	2.13742	0.42226
April	2.09282	0.16734	2.03382	0.79302
May	1.95133	0.20465	1.87482	0.72057
Jun	1.82204	0.18049	1.51122	0.93634
July	2.13561	0.13439	1.71872	0.92749
August	2.39524	0.14589	2.73267	0.84559
September	1.56413	0.21778	1.47708	0.97185
October	1.96201	0.17430	1.96294	0.84559
November	2.50054	0.10813	2.99363	0.90188
December	0.43625	0.85399	1.79919	0.16531
January	0.53753	0.79583	0.96273	0.25484
Pre-monsoon	0.97743	0.465462	0.33775	0.70507
Monsoon	0.92909	0.46303	0.47084	0.67022
Post-monsoon	0.97243	0.42589	0.37378	0.71046

Fig. 107a-l: Annual variations in selected hydrographical parameters at three stations in Veli-Aakulam estuary during Feb. 2000-Jan. 2001



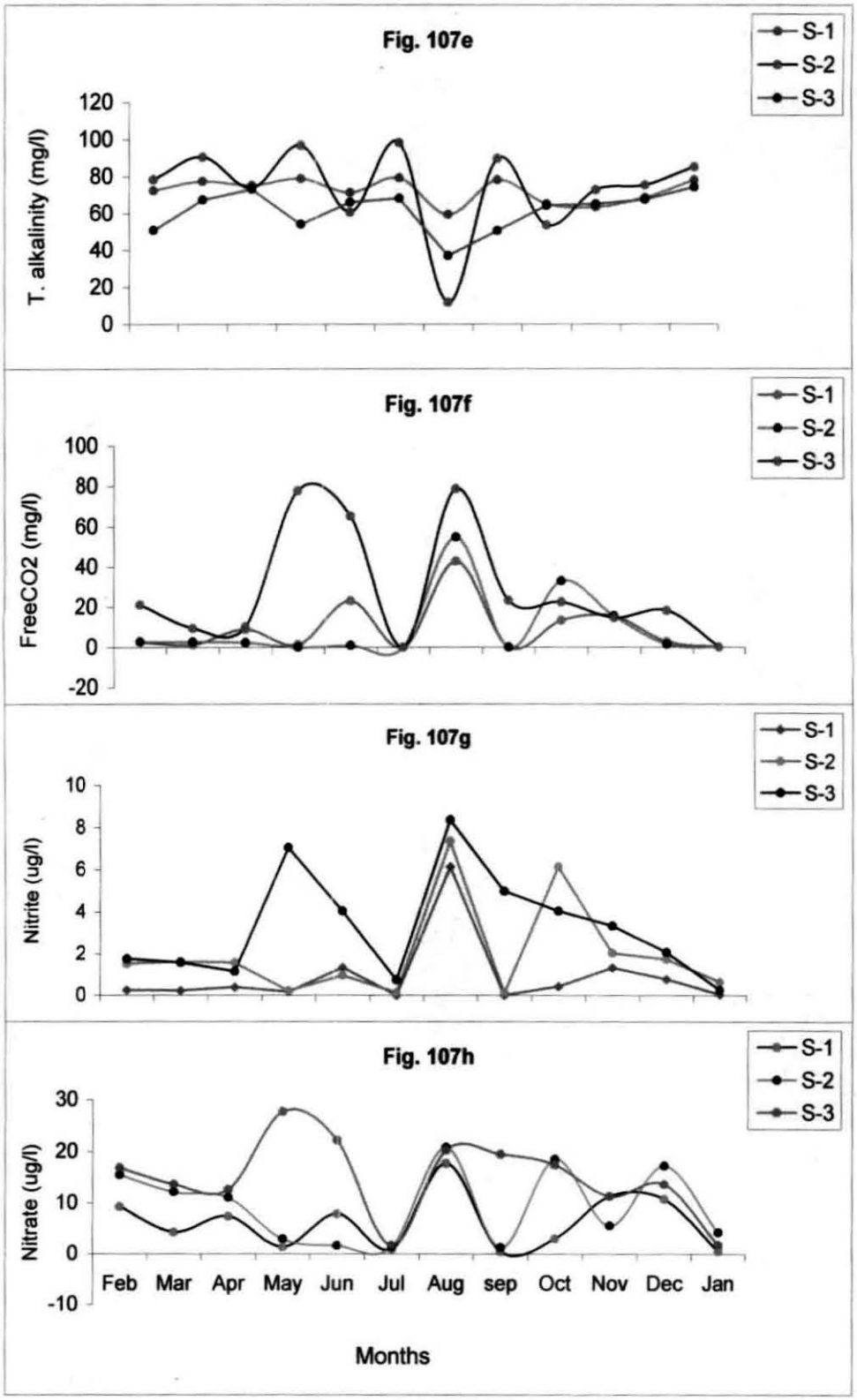


Fig. 107e
S-1
S-2
S-3
T. alkalinity (mg/l)
120
100
80
60
40
20
0
Fig. 107f
S-1
S-2
S-3
FreeCO2 (mg/l)
100
80
60
40
20
0
-20
Fig. 107g
S-1
S-2
S-3
Nitrite (ug/l)
10
8
6
4
2
0
Fig. 107h
S-1
S-2
S-3
Nitrate (ug/l)
30
20
10
0
-10
Feb
Mar
Apr
May
Jun
Jul
Aug
sep
Oct
Nov
Dec
Jan
Months

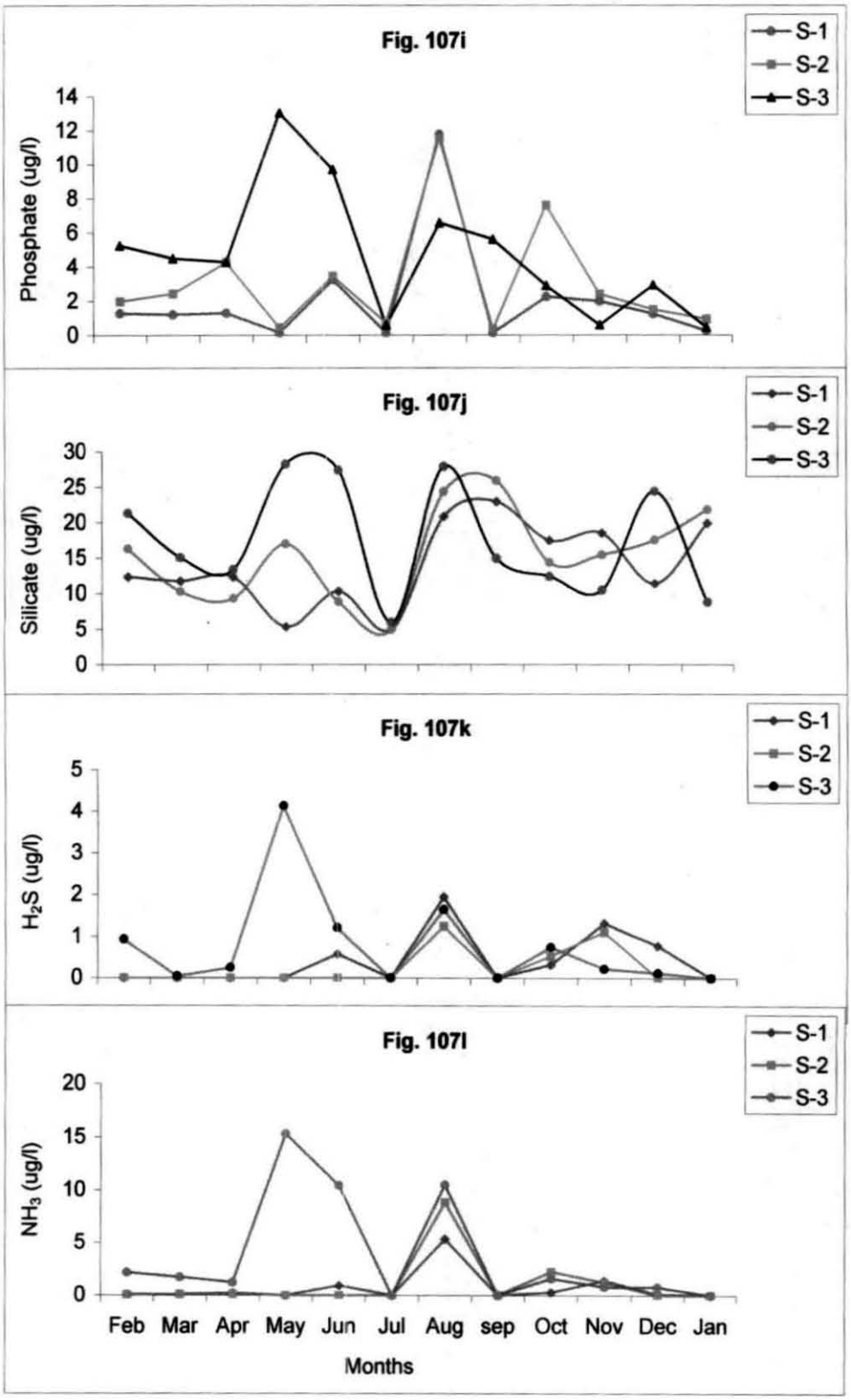


Fig. 107i
S-1
S-2
S-3
Phosphate (ug/l)
14
12
10
8
6
4
2
0
Fig. 107j
S-1
S-2
S-3
Silicate (ug/l)
30
25
20
15
10
5
0
Fig. 107k
S-1
S-2
S-3
H2S (ug/l)
5
4
3
2
1
0
Fig. 107l
S-1
S-2
S-3
NH3 (ug/l)
20
15
10
5
0
Feb Mar Apr May Jun Jul Aug sep Oct Nov Dec Jan
Months

Table.7: Monthly average of rotifers (No / m^3) at Veli-Aakulam estuary- Station I

Species	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Brachionus angularis	8054	20818	10448	9	25719	244	381	53	3099	2722	3843	14627
B. budapestinensis	-	6532	829	-	-	-	-	-	-	-	-	-
B.calyciflorus	5844	5042	9763	582	245	260	15	2	6420	24	-	170
B. falcatus	-	149	19	-	-	-	-	-	-	4	-	-
B. patulus	-	-	-	-	-	-	-	-	8	-	-	-
B. plicatilis	3157	8971	14465	50	2902	828	18	1683	299	5	67	17430
B. quadridentatus	-	10	19	-	-	-	-	-	-	-	-	-
B. murray	124	12	8	-	163	25	-	20335	38	-	1851	3668
B. rotundiformis	-	-	-	-	-	-	-	5	-	-	-	-
B.rubens	34	-	-	3	14	-	-	-	-	-	-	-
B.urceolaris	102	348	39	14	20	-	-	-	261	-	-	-
Keratella cochlearis	-	-	-	-	-	-	4	-	-	-	-	-
K. tropica	28	-	77	-	-	-	-	18	-	-	28	4
Platyias quadricornis	-	7	-	-	-	-	-	-	-	-	-	-
Monostyla bulla	-	108	-	-	-	3	2	-	11	-	-	-
Lepadella crestata	-	-	-	-	-	-	-	-	3	5	-	-
L. patella	-	-	-	-	-	-	-	-	-	-	-	-
Asplanchna brightwelli	34	278	348	-	358		3	-	-	75	18	278
Polyarthra vulgaris	141	179	38	-	29	183	2	-	-	15	7	5
Hexarthra intermedia	37	-	78	4	15	4	-	130	15	45	78	1567
Testudinella patina	-	-	13	-	-	-	6	-	-	-	-	-
Filinia longiseta	-	131	21	-	2097	38	-	-	-	-	-	-
F. terminalis	-	9658	5273	2	2058	5	-	-	-	-	-	-
F. cornuta	2	-	-	-	4	18	-	-	-	-	30	87
Scaridium longicaudum	-	-	-	-	-		-	-	3	-	-	-
Total rotifers	17557	52243	41438	664	33624	1608	431	22226	10157	2895	5922	37836
Algal bloom	-	-	-	Blue gree n	Diatom	Mixe d	-	Diatom	-	-	-	Diatom

Table.8: Monthly average of rotifers (No/m^3) at Veli - Aakulam estuary – Station II

Species	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Brachionus angularis	8054	54903	1829	20	9645	120	715	249	670	5043	3605	14339
B. budapestinensis	-	3266	95	-	-	-	-	-	-	-	-	-
B.calyciflorus	11687	5042	1717	396	245	430	100	29	2734	1661	-	444
B. falcatus	-	-	-	-	-	-	-	-	1	16	-	-
B. patulus	-	-	125	-	-	-	2	5	-	-	-	-
B. plicatilis	8593	4486	1418	11	2176	796	380	2238	821	177	373	8141
B. quadridentatus	-	-	-	3	-	-	-	-	3	-	-	26
B. murray	12	5	-	-	75	-	-	2568	-	-	96	514
B.rubens	12	5	-	-	4	-	-	-	6	-	-	-
B.urceolaris	32	-	-	10	2	323	-	-	30	-	-	-
Keratella cochlearis	-	-	-	-	-	-	-	12	-	-	-	-
K .tropica	329	-	-	-	-	-	15	-	-	-	4	15
Platyias quadricornis	-	-	-	-	-	-	-	-	7	-	-	-
L. crestata	-	-	-	5	-	-	4	-	28	4	-	-
Monostyla bulla	-	-	-	-	5	2	6	-	49	-	-	-
Lecane curvicornis	-	-	23	-	-	-	-	-	1	12	-	-
Polyarthra vulgaris	403	900	63	18	60	12	3	71	-	3	-	487
Asplanchna brightwelli	141	378	189	4	143	5	-	-	40	21	18	324
Testudinella patina	-	-	-	-	-	-	4	-	-	-	-	-
Hexarthra intermedia	11	-	-	14	24	89	3	161	537	-	17	387
Filinia longiseta	2085	3312	212	87	32	30	-	-	-	734	-	-
F. terminalis	-	11380	3226	10	3099	22	-	-	6	-	-	-
F .cornuta	4	-	-	-	44	-	-	14	-	-	52	252
Total rotifers	31363	83677	8897	578	15554	1829	1232	5347	4933	7671	4165	24929
Algal bloom	-	-	-	blue-green	Diatom	Mixed	-	Diatom	-	-	-	Diatom

Table 9a: Monthly average of rotifers (No / m^3) at Veli-Aakulam estuary – Station III

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Epiphanes macrourus	-	-	-	3	-	-	-	-	5	26	-	-
Brachionus angularis	6105	6476	67	10	522	21	25	15	100	241	1612	13530
B. budapestinensis	-	423	-	-	-	-	-	-	-	-	-	-
B.calyciflorus	270	599	23	-	-	152	-	22	5	5	170	372
B. falcatus	-	6	5	-	-	-	-	8	-	-	-	-
B. patulus	-	266	20	3	-	-	-	-	10	-	-	-
B .plicatilis	497	3	2	2	10	621	3	119	27	24	20	4214
B. quadridentatus	-	297	5	-	-	-	-	-	-	-	-	-
B. murray	-	-	-	-	-	-	-	4	-	-	-	3
B.rubens	373	-	-	-	-	-	-	-	-	-	-	-
B.urceolaris	-	-	-	-	-	-	-	-	4	4	14	-
Keratella cochlearis	-	-	-	-	3	-	-	-	-	-	-	-
K. tropica	-	17	5	-	-	-	-	-	-	-	-	-
Platyias quadricornis	15	113	5	-	-	-	-	-	5	-	-	-
P leloupi	-	-	-	-	-	-	-	-	7	-	-	-

(Continued....)

Table 9b: Monthly average of rotifers (No / m^3) at Veli-Aakulam estuary – Station III (Continuation)

Species	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Dipleuchlanis propatula	-	-	-	-	-	7	-	-	-	1	-	-
Mytilina Crassipes	-	6	-	-	-	-	-	-	-	-	-	-
M. ventralis	-	-	5	-	-	-	-	2	-	-	-	-
Lepadella ovalis	-	6	-	-	-	-	-	-	-	-	-	-
L. crestata	-	-	-	-	-	-	-	-	7	5	20	-
Monostyla bulla	30	19	15	1	-	-	-	-	5	6	-	-
Lecane curvicornis	-	6	23	-	-	-	-	-	5	-	-	-
L. luna	-	10	-	-	-	-	-	-	-	-	-	
Polyarthra vulgaris	-	47	40	1	-	175	2	-	4	2	3	205
Asplanchna brightwelli	12	34	-	-	-	-	-	3	10	-	-	172
Testudinella patina	-	-	-	-	-	-	-	-	-	-	-	-
Filinia longiseta	10	236	333	4	1	321	-	-	10	-	-	-
F. terminalis	-	4903	443	-	-	2	-	101	-	5	26	783
F. cornuta	-	-	-	-	2	-	-	3	-	4	-	130
Hexarthra intermedia	4	3	4	-	-	-	-	-	-	-	-	-
Scaridium longicaudum	-	-	-	1	-	-	-	-	-	-	-	-
Total rotifers	7260	13470	995	25	535	1299	28	277	204	310	1865	19409
Algal bloom	-	-	-	-	-	Mixed	-	-	-	-	-	Diatom

Table 10: Correlation coefficient of dominant and total rotifers with selected physico-chemical parameters of water at Veli-Aakulam estuary- Station I

Hydrographic Parameters	*B. angularis*	*B. calyciflorus*	*B. plicatilis*	*B. rotundiformis*	Total rotifers
Water temp. (°C)	-0.413	0.311	0.072	0.054	0.208
Salinity (ppt)	-0.141	-0.336	0.258	0.765**	0.122
pH	-0.069	-0.169	0.158	0.423	0.019
T. alkalinity(mg/l)	0.211	0.065	0.447	0.226	0.238
D. oxygen(mg/l)	0.119	-0.008	0.359	0.417	-0.026
Free CO_2 (mg/l)	-0.166	-0.158	-0.269	-0.211	-0.245
Nitrite(µg/l)	-0.126	-0.256	-0.287	-0.285	-0.158
Nitrate(µg/l)	-0.096	-0.104	-0.278	-0.511*	0.079
Phosphate(µg/l)	-0.179	-0.142	-0.257	-0.305	-0.157
Silicate(µg/l)	-0.257	-0.143	0.069	0.559*	-0.215
Ammonia(µg/l)	-0.236	-0.232	-0.238	-0.143	-0.329
H_2S(µg/l)	-0.257	-0.324	-0.348	-0.182	-0.258

(All statistically significant values are marked with *: if *p<0.05; If ** p<0.01)

Table 11: Correlation coefficient of dominant and total rotifers with selected physico-chemical parameters of water at Veli-Aakulam estuary- Station II

Hydrographic Parameters	*B. angularis*	*B. calyciflorus*	*B. plicatilis*	*B. rotundiformis*	Total rotifers
Water temp. (°C)	0.118	0.315	0.322	0.054	0.208
Salinity (ppt)	0.081	-0.096	0.529*	0.765**	0.121
pH	-0.033	0.015	0.303	0.423	0.019
T. alkalinity(mg/l)	0.218	0.094	0.221	0.226	0.239
D. oxygen(mg/l)	-0.039	-0.111	-0.319	0.417	-0.026
Free CO_2 (mg/l)	-0.206	-0.113	-0.263	-0.211	-0.245
Nitrite(µg/l)	-0.134	-0.001	-0.198	-0.285	-0.158
Nitrate(µg/l)	0.029	0.163	-0.273	-0.511*	0.079
Phosphate(µg/l)	-0.136	-0.039	0.075	-0.305	-0.157
Silicate(µg/l)	-0.203	-0.274	-0.310	0.559	-0.215
Ammonia (µg/l)	-0.216	-0.155	-0.301	-0.172	-0.258
H_2S(µg/l)	-0.218	-0.310	-0.311	-0.182	-0.264

(All the statistically significant values are marked with *: p<0.05; ** p<0.01)

Table 12: Correlation coefficient of dominant and total rotifers with selected physico-chemical parameters of water at Veli-Aakulam estuary- Station III

Hydrographic Parameters	*B. angularis*	*B. calyciflorus*	*B. plicatilis*	Total rotifers
Water temp. (°C)	0.224	0.341	0.115	0.239
Salinity (ppt)	0.405	0.188	0.659*	0.455
pH	0.349	0.413	0.326	0.379
T. alkalinity(mg/l)	0.310	0.322	0.352	0.556*
D. oxygen(mg/l)	0.397	0.429	0.496	0.457
Free CO_2 (mg/l)	-0.392	-0.477	-0.332	-0.417
Nitrite(µg/l)	-0.545*	-0.600*	-0.458	-0.575*
Nitrate(µg/l)	-0.444	-0.433	-0.513*	-0.495
Phosphate(µg/l)	-0.282	-0.296	-0.305	-0.309
Ammonia(µg/l)	-0.273	-0.337	-0.221	-0.424
Silicate(µg/l)	-0.043	-0.207	-0.114	-0.093
H_2S(µg/l)	-0.388	-0.523*	-0.337	-0.424

(All statistically significant values are marked with *: If * p<0.05; if ** p<0.01)

Table 13: Monthly and seasonal species diversity indices of rotifers at Veli-Aakulam estuary -Station I

Months / seasons	Shannon index	Dominance index	Species richness	Evenness index
February	1.18433	0.35373	1.02322	0.49389
March	1.59684	0.24750	1.19665	0.60508
April	1.48775	0.25761	1.31679	0.54934
May	0.52266	0.77463	0.92332	0.26858
Jun	0.88888	0.60035	1.05536	0.35768
July	1.41794	0.32821	1.21906	0.61581
August	0.47922	0.80688	0.99139	0.24627
September	0.33009	0.84278	0.59946	0.16963
October	0.90081	0.49387	1.08387	0.37567
November	0.34672	0.87419	1.00289	0.15780
December	0.82963	0.51865	0.80581	0.39895
January	1.15914	0.37280	0.75893	0.52751
Pre-monsoon	1.04495	0.38224	0.25913	0.75376
Monsoon	0.81875	0.48570	0.27357	0.59057
Post-monsoon	0.96655	0.48873	0.27403	0.69715

Table 14: Monthly and seasonal species diversity indices of rotifers at Veli-Aakulam estuary –Station II

Months / seasons	Shannon index	Dominance index	Species richness	Evenness index
February	1.39694	0.28459	1.06246	0.56217
March	1.20268	0.45873	0.79402	0.52232
April	1.63295	0.23777	0.98721	0.70918
May	1.17726	0.49591	1.57243	0.49095
Jun	1.93750	0.44418	1.24326	0.42642
July	1.51161	0.28301	1.19816	0.65648
August	1.03896	0.43875	1.26469	0.45121
September	1.08652	0.40914	0.93194	0.49453
October	1.31693	0.36540	1.52875	0.49901
November	0.96470	0.48882	0.89433	0.43905
December	0.53535	0.75794	0.71990	0.27511
January	1.09141	0.43913	0.88899	0.47399
Pre-monsoon	0.82788	0.52019	0.25571	0.59719
Monsoon	0.96418	0.47961	0.29649	0.69554
Post-monsoon	1.10163	0.41524	0.28200	0.79466

Table 15: Monthly and seasonal species diversity indices of rotifers at Veli-Aakulam estuary - Station III

Months/seasons	Shannon index	Dominance index	Species richness	Evenness index
February	0.66944	0.70437	1.01144	0.29072
March	1.34811	0.97030	1.99484	0.45785
April	1.54712	0.31762	2.17273	0.55801
May	1.66694	0.23524	1.86401	0.85664
Jun	0.16479	0.94179	0.63615	0.10239
July	1.32416	0.32174	0.83689	0.68048
August	0.34057	0.80867	0.30010	0.49124
September	1.38713	0.32808	1.42247	0.63134
October	1.76757	0.29567	2.08609	0.71132
November	0.97722	0.61674	1.74418	0.40752
December	0.63311	0.73543	0.92778	0.29494
January	0.91328	0.53532	0.70897	0.43919
Pre-monsoon	0.88658	0.44581	0.30867	0.63953
Monsoon	0.97155	0.44775	0.39116	0.70082
Post-monsoon	0.41813	0.80018	0.300305	0.30162

CHAPTER 3

EVALUATION OF THE EFFECT OF TEMPERATURE, SALINITY, FEED TYPE AND FEED CONCENTRATION ON THE REPRODUCTIVE POTENTIAL OF SELECTED ROTIFERS

INTRODUCTION

Biotic potential or reproductive potential is the inherent property of an organism to reproduce to survive, i.e., to increase in numbers. When the environment is unlimited, the specific growth rate of a population becomes constant and maximum for the existing conditions. The growth rate under favourable conditions is the maximum and is characteristic of a particular population structure. Mathematically, it is defined as the slope of the population growth curve during the logarithmic phase of growth and is symbolized by 'r' in the growth curve equation. Therefore, the population dynamics of a species in the natural habitat is generally determined by the reproductive rate of the species and the environmental resistance such as climate, density, predation, decrease in natality rates, mortality rates, scarcity of food supply etc. Moreover, 'r' summarizes all life table parameters, because it combines survival, fecundity and the timing of development and reproduction. The 'r' value of a population is estimated as the difference between the instantaneous birth and death rates. The difference between the actual reproductive rate and the reproductive potential reflects the environmental resistance. The chief environmental resistances are temperature, salinity and scarcity of food. This concept can be applied to experimental studies on population increase by varying the probable parameters or combination of parameters that have a bearing on a rate of increase of population.

Like other zooplankters, rotifers in strongly fluctuating planktonic environments have to adapt to regular colonizing events and may frequently be subjected to selection for high 'r'. Generally rotifers showed high 'r' values than that of other zooplankters due to its small size and parthenogenetic mode of reproduction.

The major factors that influence the population size in rotifer are temperature, salinity and food. Among these environmental factors, temperature plays a vital role in the reproduction of rotifers. However, only very few species have been studied to determine the relationship between 'r' and temperature under controlled conditions. *Brachionus plicatilis* and *B. calyciflorus* are the most studied. Different clones of these species have different maxima of 'r' at different temperatures (Miracle and Serra, 1989; Ignacio and Martinez, 1998). The effect of temperature on reproductive potential or 'r' of *B. plicatilis* was studied by a number of workers such as Hirayama and Ogawa (1972), James *et al.* (1983), Nagata (1985) and Snell (1986) and they concluded that temperature has a significant influence on the reproduction of this species. The highest 'r' value of 1.35 was recorded at the temperature of 35°C (Pascual and Yúfera, 1983) followed by 1.10 at 30°C (Snell, 1986) and the lowest reported 'r' value of 0.12 was noted at 10°C (Hirayama and Kusano, 1972). The highest and the lowest 'r' values of 0.77 and 0.54 were recorded at 30°C and 25°C respectively for the rotifer *B. rotundiformis* (Hagiwara *et al.*, 1995). The highest 'r' value of 2.19 for *B. rotundiformis* 'ss' type was recorded at 30°C and the lowest value of 0.40 at 19°C (Su *et al.*, 1994, 1997).

Galkovskaya (1983, 1987), Halbach (1973) and Starkweather (1987) investigated the influence of temperature on the reproductive potential of *B. calyciflorus*. According to them, the highest 'r' value of 2.95 was recorded at the temperature of 37°C (Galkovskaya, 1987) followed by 2.18 at 30°C (Galkovskaya, 1983) and the lowest 'r' value of 0.20 was recorded at 10°C (Starkweather, 1987). Similarly, the relationship between the temperature and the reproductive potential of *B. dimidiatus*, *B. angularis*, *Keratella cochlearis* and *Euchlanis dialata* was studied by King (1972, 1977), Pourriot and Rougier (1975) and Walz (1983, 1987) respectively demonstrating the significant influence of temperature on reproductive rate of rotifers. The highest 'r' for *B. dimidiatus* 1.22 was recorded at the temperature of 30°C and the lowest 'r' of 0.38 was at 20°C (Pourriot and Rougier, 1975). *B. angularis* had its highest

and the lowest 'r' values of 0.352 and -0.005 at the temperatures of 20°C and 5°C respectively (Walz, 1987). The maximum and minimum 'r' for *E. dialata* were 2.13 and 0.61, and these were noted at 27°C and 19°C respectively (King, 1972).

Like temperature, salinity also plays a vital role in the reproductive potential of an individual rotifer. Total dissolved salts and relative specific ionic concentrations are important factors conditioning rotifers in the nature (Miracle *et al.*, 1987; Mustahal *et al.*, 1991). The influence of salinity is directly related to the osmotic regulation capacity of an individual, which in turn is strongly dependent upon the genotype and the species. Osmotic regulation in rotifers has seldom been investigated. However, the studies of Kabay and Gilbert (1978), and Bayly (1972) had concluded that a number of essentially freshwater forms could also be salt tolerant to a certain extent. Nevertheless, studies on salinity effects on rotifer individuals or populations are extremely scarce (Miracle and Serra, 1989). However, a few species of rotifers especially the genus *Brachionus* have been studied to determine the relationship between the salinity and 'r' under laboratory controlled conditions. Of these, majority of the experimental studies are restricted to the halobiont rotifers such as *B. dimidiatus*, *B. plicatilis* and *B. rotundiformis* (Ito, 1960; Hirayama and Ogawa, 1972; Pourriot and Rougier, 1975; Ito *et al.*, 1981; Snell, 1986; Pascual and Yúfera, 1983; Lubzens *et al.*, 1985; Gilbert, 1991; Su *et al.*, 1994; Hagiwara *et al.*, 1995; Gopakumar *et al.*, 1998; Assavaaree *et al.*, 2003).

Pascual and Yúfera (1983), Lubzens *et al.* (1985) and Roa (1992) have found that the reproductive potential of *B. plicatilis* was highest at the salinity of 10 ppt to 20 ppt and above or below this salinity the 'r' value had deviated from its mean value. According to Ito (1960) and Lubzens (1987), the best salinity for the maximum 'r' value for *B. plicatilis* was at 19 ppt and 17 ppt respectively. However, according to Snell (1986) the optimum salinity for the highest 'r' value for *B. plicatilis* was noted at 30 ppt. All these studies had

revealed that different clones of *B. plicatilis* have different r_{max} values at different salinities. But data on 'r' for most *B. plicatilis* clones can be interpreted as an optimum curve with a maximum or a plateau located at moderate salinities between 10 ppt and 20 ppt (Miracle and Serra, 1989).

Pourriot and Rougier (1975) studied the relationship between the 'r' and salinity in *B. dimidiatus*. According to them, the highest reproductive output of this rotifer was noted at the salinities of 2 ppt (r = 0.429) and 19 ppt (r = 0.424).

Hagiwara *et al.* (1995) examined the influence of salinity and temperature on the reproductive potential of *B. plicatilis*, *B. rotundiformis* 'S' type and *B. rotundiformis* 'ss' type. According to him, the best salinity for the maximum reproductive rate of *B. plicatilis*, *B. rotundiformis* 'S' and 'ss' type were at 11 ppt (r = 0.49), 11 ppt (r = 1.37) and 11 and 22 ppt (r = 1.57 and 1.37) respectively.

Su *et al.* (1994) studied the relationship of the r_{max} of *B. rotundiformis* 'ss' type with five salinity levels, ranging from 5 ppt to 30 ppt. According to them, the optimum culture conditions for 'ss' type were at a salinity of 10 ppt to 20 ppt and at temperature of 30°C to 33°C.

The rotifer is a filter feeder and can be fed on a variety of feed types, including algae, yeast, bacteria, or inert foods such as microcapsules and detritus. Therefore, a number of workers studied the influence of feed type and feed density on the reproduction and growth in various brachionid rotifers (Erman, 1962; Hirayama and Ogawa, 1972; Hirayama and Watanabe, 1973; Hirayama *et al.*, 1973; Hirayama and Nakamura, 1976; Gatesoupe and Luquet, 1981; Joost and Schlüter, 1981; Fukusho *et al.*, 1985; Rezeq and James, 1985; , 1987; James and Rezeq, 1988; Rao and Sarma, 1988; Rafiuddin and Neelakantan, 1990; Guisande and Mazuelos, 1991; Rostock,

1995; Maruyama *et al.*, 1997; Jiakin and Xiangfei, 1998; Nandini and Rao, 1998; Navarro and Yúfera, 1998; Rumengan *et al.*, 1998; King *et al.*, 2002)

The feed type, feed concentration and particle size plays vital role in influencing the reproductive rates and other life-history parameters of rotifers (Pilarska, 1977; Rothhaupt, 1985, 1990a, b; Rafiuddin and Neelakantan, 1990; James and Rezeq, 1988; Guisande and Mazuelos, 1991; Martinez and Dodson, 1992; Rostock, 1995; Jiakin and Xiangfei, 1998). Many investigations on the effect of food quality, quantity and temperature have been conducted on *B. plicatilis*, because this species is widely used as a food for various larval fish (Lubzens, 1987). Some earlier investigations suggest that the type of algal feed has little effect on the reproductive rate of rotifers (Ito, 1960; Theilacker and McMaster, 1971; Scott and Baynes, 1978). On the other hand, Hirayama *et al.* (1979) and Snell (1986) observed that different algal foods could yield substantially different reproductive rates. Korstad *et al.* (1989) had examined the effect of diet on the lifespan, fecundity and reproductive potential of *B. plicatilis* 'S' type (= *B. rotundiformis*) and his study revealed that the reproductive rate of this rotifer was highly influenced by feed concentration and feed type. According to Hino and Hirano (1980) and Rothhaupt (1990a) particle size of the feed had been a significant influence on the ingestion by rotifers that in turn is directly related to the reproduction and growth of the individual. The particle size preference varies with the rotifer species (Rothhaupt, 1990b; Rostock, 1995; Sarma *et al.*, 1996; Jiakin and Xiangfei, 1998).

On review of literature, it is found that the investigations on the biological aspects of rotifers in India are fragmentary and incomplete. Sarma (1985, 1987) and Sarma and Rao (1990) studied the population dynamics and the influence of environmental factors on the reproduction of *B. patulus* and found that both food and temperature had a significant effect on reproduction and population growth. Gopakumar (1998) studied the reproductive potential of four different clones of *B. plicatilis* at different temperatures, salinities, feed

types and feed concentrations, and found that both salinity and feed concentration had a significant effect on their reproductive potential (r_{max}). According to him the optimum culture conditions for those four clones of *B. plicatilis* were at the salinities of 2.5 ppt, 5 ppt, 10 ppt and 17 ppt respectively and at temperature between 28°C and 32°C. Thus, despite the studies on the above species our present knowledge on the reproductive biology of rotifers from Kerala is scarce. However, the determination of the reproductive potential for a specific rotifer species under controlled conditions is the key to developing mass culture of the potential rotifer species since a suitable sized, nutritionally enriched live food organism is the major requirement for the mass rearing of many finfish larvae. Hence, the results of this study on the impact of salinity, temperature, feed type and feed concentration on the reproductive potential of six rotifer species namely *Brachionus angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis*, *B. murray* and B. *rotundiformis* is presented in this chapter.

MATERIAL AND METHODS

A total of six rotifer species namely *Brachionus angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis*, *B. murray* and *B. rotundiformis* were employed for the present study. Of these *B. calyciflorus*, *B. plicatilis, B. murray*, and *B. rotundiformis* were collected from Veli - Aakulam estuary, whereas *B. angularis* and *B. caudatus* were collected from Poonthura estuary. These experimental animals were cultured in the laboratory using a starter culture of amitic female cloned from local plankton. The rotifers, *B. angularis*, *B. caudatus* and *B. calyciflorus* were fed with *Chlorella ellipsoidea* and maintained at room temperature (28-30°C). Similarly, *B. plicatilis*, *B. murray* and *B. rotundiformis* were fed with *C. salina* and the stock cultures were maintained at room temperature in the laboratory for feeding experiments.

Salinity, temperature, feed concentration and type of feeds were the variables tested in these experiments. Based on a series of salinity tolerance tests, three salinities were selected for *B. angularis*, *B. caudatus* and *B. calyciflorus* while a total of six salinity levels were chosen for *B. plicatilis*, *B. murray* and *B. rotundiformis*. The salinity levels chosen for *B. plicatilis* and *B. murray* were 0.5 ppt, 5 ppt, 10 ppt, 15 ppt, 25 ppt and 35 ppt those chosen for *B. rotundiformis* were 2 ppt, 5 ppt, 10 ppt, 15 ppt, 25 ppt and 35 ppt. The experimental salinity levels chosen for *B. caudatus* and *B. calyciflorus* were 0.5 ppt, 5 ppt and 7 ppt; those chosen for *B. angularis* were 0.5 ppt, 5 ppt and 10 ppt.

Four different freshwater feed types namely *Chlorella ellipsoidea*, *Ankistrodesmus convolutus*, *Chlorococcum infusorium* and *Scenedesmus protuberans* were employed for *B. angularis*, *B. caudatus* and *B. calyciflorus*. On the other hand, six marine algal diets were used for the other rotifers. They were *Chlorella salina*, *C. infusorium*, *Tetraselmis gracilis*, *Isochrysis galbana* and *Chaetoceros calcitrans*. All the algal cultures were maintained in the laboratory by using Walne's medium and in constant light. The stock cultures of *C. ellipsoidea*, *C. salina* and *A. convolutus* were obtained from the Vizhinjam Research Centre of CMFRI. The marine algal cultures of *C. calcitrans*, *I. galbana* and *T. gracilis* were obtained from CMFRI headquarters, Kochi and the rest of the algae, i.e., *S. protuberans* and *C. infusorium were* isolated from local water bodies by serial dilution method as described by Vonshak (1986). The required cell concentrations were prepared by centrifuging the algal cultures at 3000 rpm and then introduced the cells into the experimental vials of appropriate salinities and their cell counts were taken with a hemocytometer.

The experimental feed concentrations employed for microalgae were as follows:

Chlorella ellipsoidea: 1×10^6, 2×10^6, 3×10^6, 4×10^6, 6×10^6, 8×10^6, 10×10^6 and 12 $\times 10^6$ cells/ml.

Chlorella salina:	2×10^6, 4×10^6, 6×10^6, 8×10^6, 10×10^6 and 15×10^6cells/ml.
Chlorococcum infusorium:	1×10^6, 2×10^6, 3×10^6, 4×10^6, 6×10^6, 8×10^6, 10×10^6 and 12×10^6 cells/ml.
Scenedesmus protuberans:	$1x\ 10^6$, 2×10^6, 3×10^6, 4×10^6, 5×10^6, 6×10^6, 8×10^6 and 10×10^6 cells/ml.
Ankistrodesmus convolutus:	1×10^6, 2×10^6, 3×10^6, 4×10^6, 5×10^6, 6×10^6, 8×10^6 and 10×10^6 cells/ml.
Tetraselmis gracilis:	0.5×10^6, 1×10^6, 2×10^6, 3×10^6, 5×10^6 and 9×10^6 cells/ml.
Chaetoceros calcitrans:	0.5×10, 1×10^6, 2×10^6, 3×10^6, 5×10^6 and 8×10^6 cells/ml.
Isochrysis galbana:	1×10^6, 2×10^6, 3×10^6, 4×10^6, 5×10^6 and 9×10^6 cells/ml.

Of these, *C. infusorium* grew well in a wide range of salinity from zero ppt to 35 ppt and hence this alga was employed for both freshwater and halobiont rotifers. The cell concentrations of *C. infusorium* were chosen for the halobiont rotifers were 1×10^6, 2×10^6, 4×10^6, 6×10^6, 8×10^6 and 10×10^6 cells/ml. The experiment was conducted at three temperatures: 25 ± 1°C, 29 ± 1°C and 35 ± 1°C in thermostatically controlled water baths under continuous illumination. The rotifers were acclimatized to the experimental salinities, temperature and feed concentrations for one week before starting the experiments. Five ml of the medium of each feed type with appropriate feed concentrations and salinities corresponding to the rotifer species were taken in vials. The five numbers of previously acclimatized amitic females (with a single egg) of each rotifer species (one animal/one ml) was carefully transferred to the appropriate medium with a micropipette. Each set of experiment was carried out in triplicate and the mean values were taken. For *B. angularis*, *B. caudatus* and *B. calyciflorus* a total of 216 vials were set up for each rotifer as follows: 1 feed type x 8 feed concentrations x 3 salinities x 3 temperatures x 3 replicates. For *B. plicatilis*, *B. murray* and *B. rotundiformis* a

total of 324 vials were set up as follows for each taxon: 1 feed type x 6 feed concentrations x 6 salinities x 3 temperatures x 3 replicates. After three days (72 hours incubation) the number of females vial were counted and the reproductive potential was calculated according to the formula:

$$r = \frac{\ln (Nt) - \ln (N0)}{t}$$

Where, r = instantaneous growth rate; ln (Nt) = natural logarithm of number of females after 't' time; ln (No) = natural logarithm of initial number of females; t = duration of experiment (3 days).

The reproductive potential in relation to feed concentration, salinity and temperature was studied by three- way ANOVA (Using SYSTAT ver.7.0)

RESULTS

Brachionus angularis

The reproductive potential value (mean 'r') of *B. angularis* in different feed concentration, temperature, salinity and feed types is presented in Figs. 108a-c to 11a-c. The results indicated that salinity, temperature and food had significant effect on the reproductive potential of *B. angularis*. The highest 'r' was found at room temperature (28-30°C) and at salinity of 0.5 ppt for all the feed concentrations. All the experiments showed that the mean 'r' values increased with increasing cell densities of the algal food. Rotifers fed on *Chlorella ellipsoidea* and *Chlorococcum infusorium* showed an increase in mean number and mean 'r' values between 1 x 10^6 and 4 x 10^6 cells/ml and between 1 x 10^6 and 3 x 10^6 cells /ml respectively, but no further significant increase in 'r' was observed at concentrations above this level. Similarly, rotifers fed on *Ankistrodesmus convolutus* and *Scenedesmus protuberans* showed an increase in 'r' values between 1x 10^6 cells/ml and 3 x 10^6 cells/ml

and between 1 and 2 x 10^6 cells/ml respectively, and beyond these concentrations the 'r' value declined in all the tested temperatures and salinities. The rotifers fed on *C. ellipsoidea* tended to have the highest 'r' value (1.74) when compared to those fed on *C. infusorium* (1.58), *A. convolutus* (1.57) and *S. protuberans* (0.92). The 'r' values for the best salinity of 0.5 ppt x feed concentration combination with *C. ellipsoidea* (4 x 10^6 cells/ml), *A. convolutus* (3 x 10^6 cells/ml), *S. protuberans* (1 x 10^6 cells/ml) and *C. infusorium* (3 x 10^6 cells/ml), at room temperature were 1.74, 1.57, 0.92 and 1.57 respectively and the same at lower temperature of 24 - 26°C were 1.27, 1.27, 0.82 and 0.86 respectively. The 'r' values for the best salinity x feed concentration combination with the above mentioned algal food at thermostat temperature of 35 - 37°C were 0.89, 1.03, 0.79 and 1.26 respectively.

Results of the three way analysis of variance (Tables 16 - 19) showed significant influence of feed concentration ($p<0.01$), salinity ($p<0.01$), salinity x feed concentration ($p<0.01$) and feed concentration x salinity x temperature ($p<0.01$) were significantly influenced the 'r' value of *B. angularis* in all the treatments.

Brachionus caudatus

The reproductive potential values of *B. caudatus* (mean 'r') in different feed type and feed concentrations at three temperature and salinity are given in Fig. 112a-c to 115a-c. The salinity that gave the r_{max} was at 0.5 ppt for all the feed types and feed concentrations. The reproductive rate declined as the salinity increased and the least 'r' value was noted at the highest salinity of 7 ppt for all types of the feed and feed concentrations. Similarly, all the types of feed gave the highest 'r' value at room temperature (28-30°C). The feed concentrations in which the highest 'r' value were noted for the feed types *C. ellipsoidea*, *C. infusorium*, *A. convolutus* and *S. protuberans* were 4 x 10^6 cells/ml, 4 x 10^6 cells/ml, 3 x 10^6 cells /ml and 1 x 10^6 cells /ml respectively. Rotifers fed on *C. ellipsoidea* and *C. infusorium* showed an increase in

reproductive rate between 1 and 4 x 10^6 cells /ml, but no further significant increase in 'r' was observed above this concentration of this feed type. The 'r' values of rotifers fed on *A. convolutus* showed an increasing trend between 1 x 10^6 cells/ml and 3 x 10^6 cells/ml but the rate declined significantly above 3 x 10^6 cells/ml of this feed. The rotifers fed on *S. protuberans* showed a similar trend. The 'r' values increased between 1 x 10^6 and 2 x 10^6 cells/ml, and above this concentration the reproductive rate was significantly reduced at all the tested temperatures. The 'r' values for the best salinity (0.5 ppt) x feed concentration combinations with *C. ellipsoidea*, *C. infusorium*, *A. convolutus* and *S. protuberans* were 1.47, 1.30, 1.24 and 0.94 at room temperature and the same at lower temperature were 1.30, 0.86, 0.99 and 0.79. At higher temperature the 'r' values for the best salinity x feed concentrations with *C. ellipsoidea*, *C. infusorium*, *A. convolutus* and *S. protuberans* were 1.12, 1.03, 1.08 and 0.83 respectively.

The three way analysis of variances (Tables 20 to 23) showed that the interactions of salinity x feed concentration ($p<0.01$), feed concentration x temperature ($p<0.01$), salinity x temperature ($p<0.01$) and feed concentration x salinity x temperature ($p<0.01$) were significant for *A. convolutus and S. protuberans*. However, the interaction of salinity x feed concentrations x temperature was not significant for *C. ellipsoidea* and *C. infusorium*.

Brachionus calyciflorus

The data for assessing the effects of temperature, salinity, feed type and feed concentrations on reproductive potential of *B. calyciflorus* are given in Fig. 116a-c to 119a-c with the results of analysis of variance presented in Tables 24 to 27. The salinity that yielded the highest 'r' value for all the types of feed and feed concentrations was 0.5 ppt. The highest 'r' value for all treatments was noted at room temperature (28°C to 30°C). Among the different algae used for the experiment, rotifers fed on *C. ellipsoidea* tended to

have the highest 'r' (1.91) when compared to those fed on *A. convolutus* (1.83), *S. protuberans* (1.62) and *C. infusorium* (1.77) respectively. The experiments showed that the mean 'r' values increased with increasing feed concentrations irrespective of salinity and temperatures. Rotifers fed with *C. ellipsoidea* and *C. infusorium* showed an increase in 'r' values between 1 x 10^6 and 8 x 10^6 cells/ml, but no further significant increase in 'r' was observed above this feed concentration. Likewise, rotifers fed with *A. convolutus* showed a similar trend in 'r' values at algal cell densities upto the cell concentration of 5 x 10^6, and above this density level the 'r' values declined. Rotifers fed on *S. protuberans* showed an increase in 'r' values between 1 x 10^6 and 4 x 10^6 cells/ml and beyond this level the 'r' decreased. The highest 'r' values for the best salinity x feed concentration combinations with *C. ellipsoidea*, *A. convolutus*, *S. protuberans* and *C. infusorium* at room temperature of 28 - 30°C were 1.91, 1.83, 1.62 and 1.77 respectively and the same at thermostat temperature of 35 - 35°C were 1.67, 1.75, 1.53 and 1.76 respectively. However, at the lower temperature (24 - 26°C) all the feed types yielded the minimum values irrespective of the salinity and feed concentrations.

Analysis of variance showed that the interaction of feed concentration x salinity ($p<0.01$), feed concentration x temperature ($p<0.01$), salinity x temperature ($p<0.01$) and feed concentration x salinity x temperature ($p<0.01$) were significant for all the feed types.

Brachionus plicatilis

The reproductive potential values (mean 'r') for different type of feeds, feed concentrations, salinities and temperatures are presented in Fig. 120a-c to 124a-c. The salinity that gave the maximum reproductive potential for all the feed types and feed concentrations was 5 ppt. The 'r' values declined as the salinity increased from this level. The least 'r' values were noted at the highest salinity of 35 ppt for all the types of feed and feed concentrations.

Among the microalgae *C. infusorium* gave the highest 'r' at all the tested temperature. The feed concentration in which the highest 'r' were noted for the feed types *C. salina*, *I. galbana*, *T. gracilis*, *C. infusorium* and *C. calcitrans* at room temperature were 4 x 10^6 cell/ml, 2 x 10^6 cells/ml, 1 x 10^6 cells/ml, 4 x 10^6 cells/ml and 1 x 10^6 cells/ml respectively and the same at thermostat temperature were 4 x 10^6 cells/ml, 2 x 10^6 cells/ml, 1 x 10^6 cells/ml, 4 x 10^6 cells/ml and 1 x 10^6 cells/ml respectively. However, at lower temperature in most cases the feed concentration showed marginal decrease from corresponding feed concentration at room temperature. The 'r' values for the best salinity x feed concentration combinations with *C. salina*, *I. galbana*, *T. gracilis*, *C. infusorium* and *C. calcitrans* at room temperature were1.43, 1.42, 1.18, 1.47 and 1.03 respectively and the same at lower temperature and thermostat temperature were 1.02 and 0.80, 1.04 and 0.81, 0.97 and 0.94, 1.14 and 0.78 and 0.97 and 0.82 respectively.

Analysis of variance (Table 28 to 32) showed that the interactions of feed concentration x salinity ($p<0.01$), feed concentration x temperature ($p<0.01$), temperature x salinity ($p<0.01$) and feed concentration x salinity x temperature ($p<0.01$) were also significant for all the types of feeds.

Brachionus murray

The mean 'r' value for the different types of feed, feed concentrations, salinities and temperatures is presented in Fig. 125a-c to 129a-c. The salinity which gave the maximum reproductive potential for all the feed types and feed concentrations was 10 ppt. The 'r' values declined as the salinity decreased or increased from this level. The least 'r' values were noted at the highest salinity (35 ppt) for all the types of feed and feed concentrations. Among the microalgae *Chaetoceros calcitrans* gave the highest 'r' of 1.22, 1.74 and 1.59 at 24 - 26°C, 28 - 30°C and 35 - 37°C respectively. The feed concentration in which the highest 'r' was noted for the feed types *C. calcitrans*, *I. galbana*, *T. gracilis*, *C. infusorium* and *C. salina* at room temperature were 2 x 10^6 cell/ml,

2 x 10^6 cells/ml, 1 x 10^6 cells/ml, 4 x 10^6 cells/ml and 4 x 10^6 cells/ml respectively at room temperature. However, at lower and higher temperatures in most cases the feed concentration showed marginal decrease or increase from the corresponding values at room temperature. The 'r' values for the best salinity x feed concentration combinations with *C. calcitrans*, *I. galbana*, *T. gracilis*, *C. infusorium* and *C. salina* at room temperature were1.74, 1.54, 1.51, 1.33 and 1.46 respectively, and the same at lower temperature and thermostat temperature were 1.22 and 1.59; 0.97 and 1.49; 0.75 and 1.38; 0.84 and 1.21 and 0.83 and 1.29 respectively.

Analysis of variance (Table 33 to 37) showed that the interaction of feed concentration x salinity $p<0.01$), feed concentration x temperature ($p<0.01$), temperature x salinity ($p<0.01$) and feed concentration x salinity x temperature ($P<0.01$) were significant for all the types of feed.

Brachionus rotundiformis

The mean 'r' values for different feed concentration, feed type, salinity and temperature are given in Fig. 130a-c to 134a-c. The salinity that gave the highest 'r' value was 15 ppt for all the feed types and feed concentrations. The 'r' values declined at the salinities above or below this level. All the types of feed gave the highest 'r' values at room temperature and at thermostat temperature. The least 'r' values for all the feed type were noted at lower temperature (24 - 26°C). Among the different algal diets employed for the study, rotifers fed on *I. galbana* tended to have the highest 'r' (1.83) when compared to those fed on *T. gracilis* (1.78), *C. salina* (1.50), *C. infusorium* (1.38) and *C. calcitrans* (1.32). Rotifers fed on *I. galbana*, *T. gracilis* and *C. calcitrans* showed an increase in 'r' values between 0.5 x 10^6 cell/ml and 2 x 10^6 cells/ml, but no further significant increase in 'r' was observed at above 2 x 10^6 cells/ml. Similarly, rotifers fed on *C. infusorium* and *C. salina* showed an increase in 'r' values between 2 x 10^6 cells/ml and 4 x 10^6 cells/ml and 1 x 10^6 and 4 x 10^6 cells/ml; beyond this level 'r' values declined. The r_{max} values for

the best salinity (15 ppt) x feed concentration combination with *I. galbana* (2 x 10^6 cells/ml), *T. gracilis* (1 x 10^6 cells/ml), *C. infusorium* (4 x 10^6 cells/m), *C. salina* (4 x 10^6 cells/ml) and *C. calcitrans* (1 x 10^6 cells/ml) at room temperature were 1.83, 1.78, 1.50, 1.38 and 1.32 respectively and the same at the higher temperature were 1.83, 1.41, 1.36, 1.48 and 1.30 respectively. The r_{max} values for the best salinity x feed concentration combination with those feed types at lower temperature were 1.03, 0.91, 0.76, 0.96 and 0.69 respectively.

The results of the three way analysis of variances (Table 38 to 42) showed that the interactions of feed concentration x salinity ($p<0.01$), feed concentration x temperature ($p<0.01$), temperature x salinity ($p<0.01$) and feed concentration x salinity x temperature ($p<0.01$) were significant for *C. salina*, *T. gracilis*, *C. infusorium*, *C. calcitrans* and *I. galbana*.

DISCUSSION

The experiments showed that the reproductive potential of *Brachionus* species depended on the temperature, salinity, feed type and feed concentration. On the basis of laboratory studies it may be concluded that temperature had a direct effect on reproductive rate of rotifers. The least and highest r_{max} values for *B. angularis*, *B. plicatilis* and *B. caudatus* were recorded at thermostat (35 - 37°C) and room temperatures (28 - 30°C) respectively, whereas the same for *B. calyciflorus*, *B. murray* and *B. rotundiformis* were recorded at lower (25 - 26°C) and room temperatures (28 - 30°C). The present results had confirmed the findings of Miracle and Serra (1989) who concluded that warmwater- adapted rotifer species (tropical rotifers) show their highest or maximum 'r' values at temperature over 27°C. According to Snell (1986) and Gopakumar (1998) the highest r_{max} value for *B. plicatilis* was noted at 30°C. Galkovskaya (1987) had observed that the rotifer *B. calyciflorus* recorded its highest 'r' value (2.95) at the temperature of 30°C.

Sú *et al.* (1994), Hagiwara *et al.* (1995) and Assavaaree *et al.* (2003) had suggested that the most suitable temperature for the maximum reproductive potential of *B. rotundiformis* 'S' type and *B. rotundiformis* 'ss' type were at temperature above 30°C. According to Walz (1987) the best temperature for maximum 'r' value for *B. angularis* was 25°C but in the present study the highest 'r' value of this taxon was recorded at room temperature (28 - 30°C), and this difference may be attributed to the clone selection at the environmental temperatures of origin and the interaction of food with temperature, since different strains or clones of these species have different 'r' maxima at different temperatures. However, the direct effect of temperature on 'r' of rotifers is difficult to determine since it is mainly affected by population density and food supply. The influence of temperature could be inferred from the response manifesting as developmental rates or metabolic activities to increasing temperature, and the resultant 'r' values reaching a maximum. Beyond this point 'r' sharply decreases. The optimum temperature is the upper limit for the normal functioning of the animal in the particular set of rearing conditions, which in turn depend on the genotype.

The present investigation showed a strong influence of salinity on 'r' of all the rotifer species studied. *B. angularis*, *B. caudatus* and *B. calyciflorus* yielded their highest 'r' value at the salinity of 0.5 ppt, and above this level their 'r' declined irrespective of the optimum conditions of temperature, feed type and feed concentration. On the other hand, the haline rotifers *B. plicatilis*, *B. murray* and *B. rotundiformis* recorded their highest 'r' values at the salinities of 5 ppt, 10 ppt and 15 ppt respectively, and above or below these levels their 'r' values decreased. Thus the present study is in agreement with the findings of Miracle and Serra (1989) and Serra *et al.* (1998) concluded that the direct effect of salinity on 'r' values dependended on the species and genotype. The influence of salinity is directly correlated with the osmo-regulatory capacity of the rotifers, which in turn is strongly dependent on the genotype. The genotype is adapted to an optimum salinity in which 'r' is high. Then 'r' decreases as salinity conditions move away from this optimum due to

a decrease in fertility and survival. Pourriot and Rougier (1975), Aranovich and Spektorova (1974) and Miracle *et al.* (1987) had observed that the reproductive rate and survival of *B. dimidiatus*, *B. calyciflorus* and *B. angularis* decreased as the salinity increased from 0.5 ppt to 9 ppt, 2 ppt to 10 ppt and 0.5 ppt to 24 ppt respectively. Hagiwara *et al.* (1995) had observed that the optimum salinity for the best 'r' for *B. plicatilis*, *B. rotundiformis* (both 'S' and 'ss' type) were at 10 ppt and 11 ppt to 22 ppt respectively.

Both feed type and feed concentration are crucial factors in determining the reproductive potential of different rotifer species. The highest and the lowest reproductive potential values of *B. angularis*, *B. caudatus* and *B. calyciflorus* were observed on the diets of *C. ellipsoidea* and *S. protuberans* respectively. The present observations support the findings of Rothhaupt (1990), Martinez and Dodson (1992), Rostock (1995), Ignacio and Martinez (1998), Jiakin and Xiangfei (1998) and Yilong (1999) who reported that the algal species such as *Chlorella vulgaris*, *C. ellipsoidea*, *C. pyrenoidosa*, *Cyclotella meneghiniana*, *Scenedesmus acutus*, *S. obloquies* and *Chlamydomonus* spp., *Oocystis elliptica*, *Chlorophyceans*, *Nannochloris* sp. etc. are ideal food sources for the freshwater rotifers especially for *B. rubens*, *B. angularis*, *B. quadridentatus* and *B. calyciflorus*.

The highest 'r' value for *B. plicatilis* previously reported was 1.40 and 1.36 by Gopakumar (1998) on the diet of *C. marina* and *Tetraselmis gracilis* but in the present study, the feed type did not show much variation between the tested algal diets except on the diet of *C. calcitrans*, in which the least 'r' value was noted. However, *Tetraselmis*, *Isochrysis, Chlorella capsulate, Chlorogibba trochisciaeformis* and *Chlorella* had been commonly used as a nutritious food for *B. plicatilis* by many researchers (Trotta, 1983; Okaushi and Fukusho, 1984; Fukusho *et al.*, 1985; Rezeq and James 1985, 1987; James and Rezeq, 1988; Rafiuddin and Neelakantan, 1990).

During the present investigation it was observed that the rotifer *B murray* (= *B. rotundiformis* 'S' type) fed on *C. calcitrans* had recorded its highest reproductive rate and not on the feed *Isochrysis galbana*. Earlier investigation (Korstad *et al.*, 1989; Hagiwara *et al.*, 1995), on the contrary, had suggested that *I. galbana* and *Nannochloropsis oculata* were the most suitable diets for optimum reproductive potential of *B. rotundiformis*. However, the present findings corroborate the observations that the abundance of this species was always associated with diatom bloom especially that of *Chaetoceros* spp. in its natural habitat. Haberman and Sudzuki (1998) noticed a similar observation from Japan. Therefore, the substantial variation recorded may be attributed to geographical strain variation of this taxon.

According to Su *et al.* (1994) and Rumengan *et al.* (1998) the suitable feeds were *Isochrysis galbana*, *Nannochloropsis* spp. and *Tetraselmis* spp. for the optimum population growth and reproductive rate for *B. rotundiformis* 'ss' type. In the present study, the algal diets such as *I. galbana*, *C. salina* and *T. gracilis* yielded the highest 'r' values for *B. rotundiformis* (= *B. rotundiformis* 'ss' type) and this is in agreement with the findings of above mentioned authors.

The concentration of the feeds had a significant influence on 'r', which is dependent on the type of the feed (James *et al.*, 1983). Hence the concentration of feed required for the highest 'r' value varies with the particle size of the feed. Among the freshwater algal species *S. protuberans* (30 - 37 µm) is larger than *C. ellipsoidea* (2 - 5 µm), *Chlorococcum infusorium* (2 - 7 µm) and *Ankistrodesmus convolutus* (10 - 20 µm) and hence its concentration requirements is proportionately lower than that of *C. ellipsoidea* and *A. convolutus* for *B. calyciflorus*, *B. angularis* and *B. caudatus*. However, the least 'r' values for *B. angularis* and *B. caudatus* were obtained on the diet of *S. protuberans* at a cell concentration of 1 x 10^6, and that can be attributed to the particle size of this alga being too big for the ingestion by these rotifers. The present observation is in conformity with the findings of Hino and Hirano

(1980), Rothhaupt (1990) and Jiakin and Xiangfei (1998) who observed that *B. angularis* and *B. plicatilis* were preferred food items ≤ 5 µm in mean diameter, whereas *B. calyciflorus*, *B. rubens* and *B. quadridentatus* were preferred food items ≤ 15 µm in mean diameter. Among the marine algae employed for the present study, the alga *T. gracilis* had the larger size (14 - 30 µm) than that of *C. salina* (2 - 5 µm), *I. galbana* (3 - 7 µm) and *C. calcitrans* (3 - 6 µm) and hence its concentration requirement is comparatively less than that of *C. salina* and *I. galbana* for all the three haline rotifer species studied.

The increase in the reproductive rate of all the rotifer species studied corresponded with the increase in cell number of algal diets as evident from the present observations. The 'r' values of the rotifers showed a curvilinear relationship with algal cell density where the 'r' values increased with corresponding increase in cell densities of the feed (Rafiuddin and Neelakantan, 1990). However, at higher concentrations (beyond the optimum concentration which varied with size of the algae and rotifer species) of the feed the 'r' value declined or became less pronounced in all the treatments. The present observation is in agreement with the findings of Yúfera and Pascual (1985) who observed that ingestion increases with food density at lower concentrations and remains constant or declines at higher algal densities since the growth and reproduction are directly dependent on the food consumption of the rotifers. Among the interactions of different parameters, feed concentration x salinity, feed concentration x temperature and feed concentration x salinity x temperature were significant for most of the rotifers. The results of this study show the effectiveness of various foods, which in turn are available as a food source for rotifers.

Fig. 108a-c: Reproductive potential ('r') of *Brachionus angularis* at different salinities and feed concentrations of *Chlorella ellipsoidea* at three temperatures

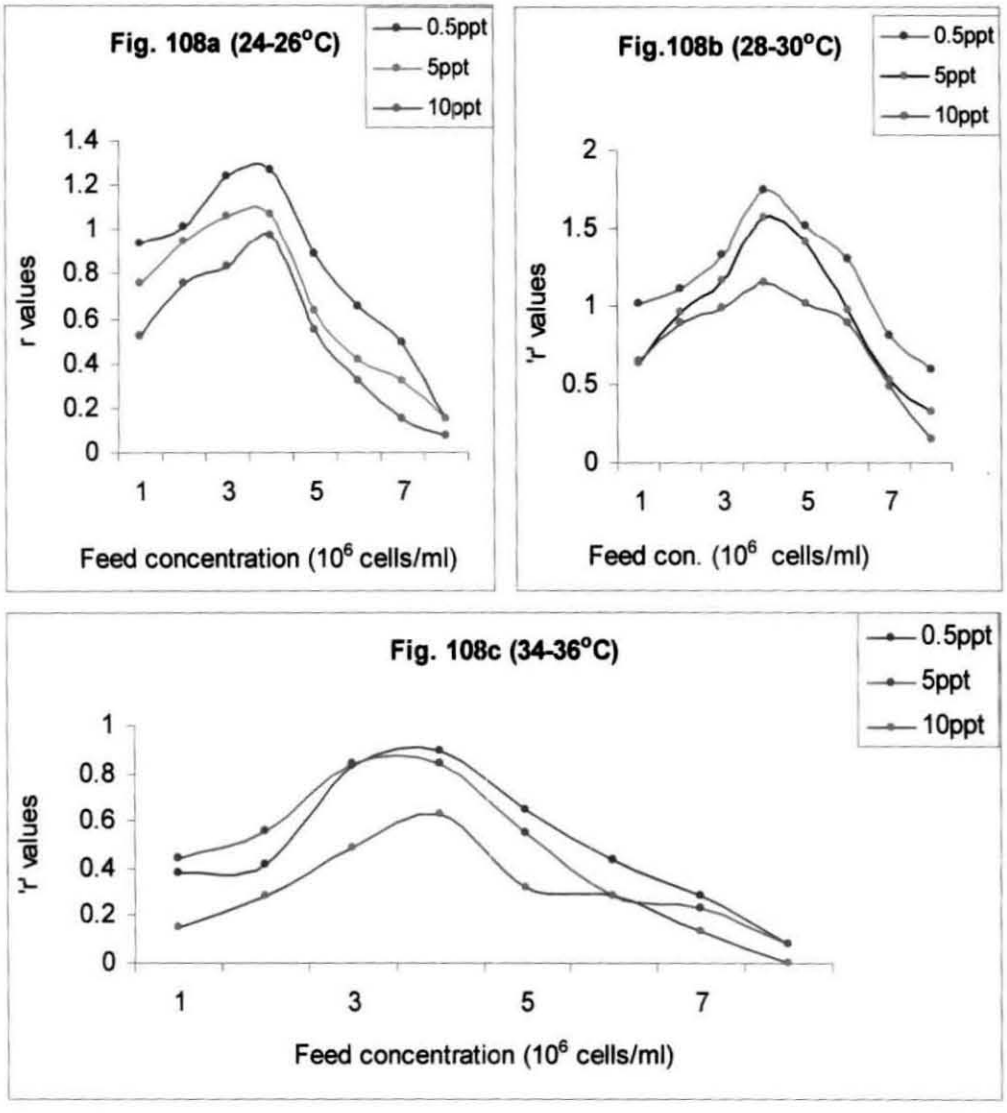


Table 16: Result of three-way ANOVA comparing the reproductive potential of *B. angularis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	14419.59	2	7560.15	46.79	0.00**
Feed concentration	52921.07	7	7209.79	49.07	0.00**
Temperature	37707.62	2	18853.81	122.38	0.00**
Salinity x Feed concentration	15167.22	14	1083.81	7.03	0.00**
Feed concentration X Temperature	44002.08	14	3143.01	20.40	0.00**
Salinity x Temperature	10662.05	4	2665.51	17.30	0.00**
Salinity X Feed concentration x Temp	16518.25	28	589.94	3.83	0.00**
Error	22184.67	144	154.06		

(* $p<0.05$; ** $p<0.01$)

Fig. 109a-c: Reproductive potential ('r') of *B. angularis* at different salinities and feed concentrations of *Ankistrodesmus convolutus* at three temperatures

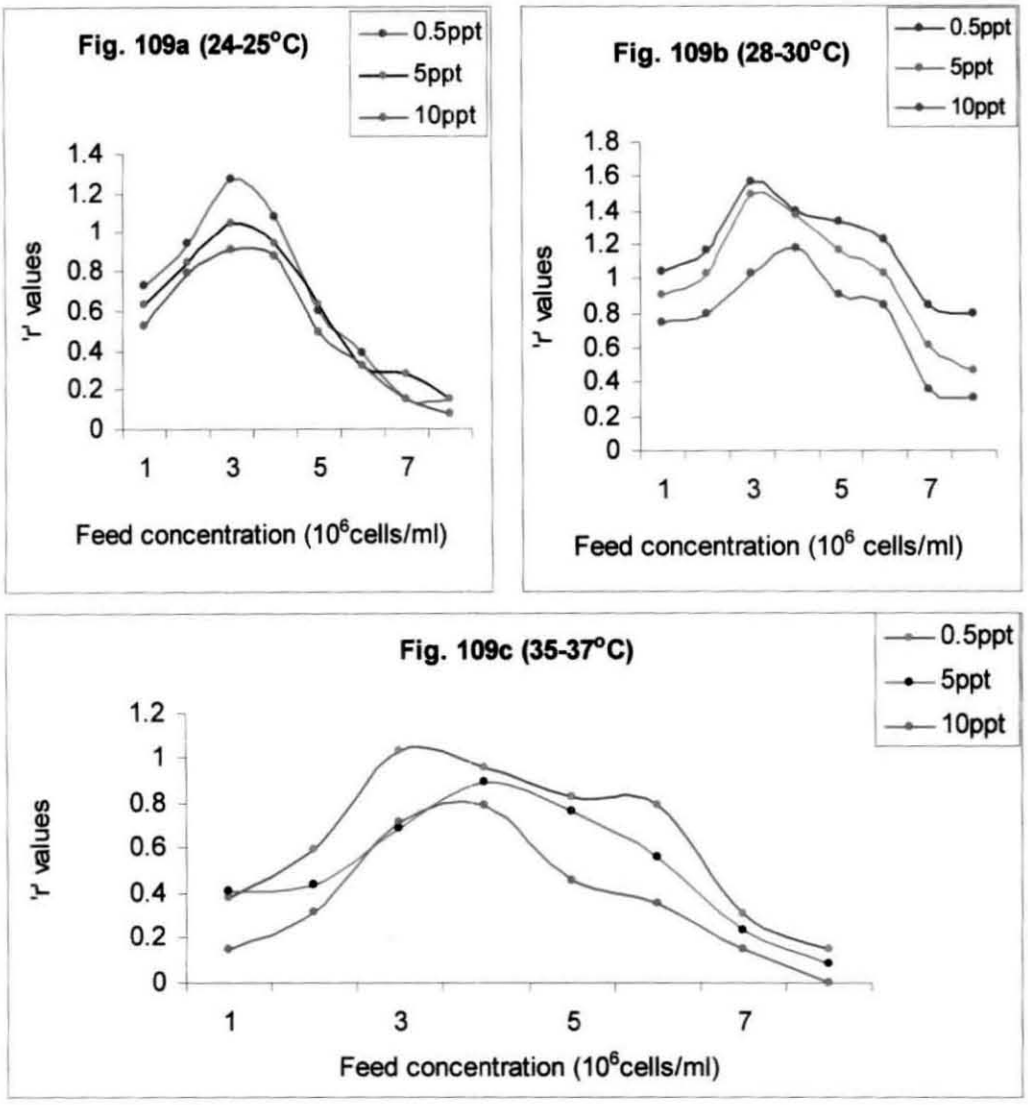


Table 17: Result of three-way ANOVA comparing the reproductive potential of *B. angularis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	6307.53	2	3153.76	43.55	0.00**
Feed concentration	33194.65	7	742.09	65.49	0.00**
Temperature	16610.08	2	305.04	144.69	0.00**
Salinity x Feed concentration	5246.99	14	364.79	5.18	0.00**
Feed concentration X Temperature	19348.66	14	382.05	19.09	0.00**
Salinity x Temperature	3268.47	4	817.12	11.28	0.00**
Salinity X Feed concentration x Temp	4026.12	28	143.79	1.99	0.05*
Error	10427.33	144	72.41		

(* p<0.05; **p<0.01)

Fig. 110a-c: Reproductive potential ('r') of *B. angularis* at different salinities and feed concentrations of *Scenedesmus protuberans* at three temperatures

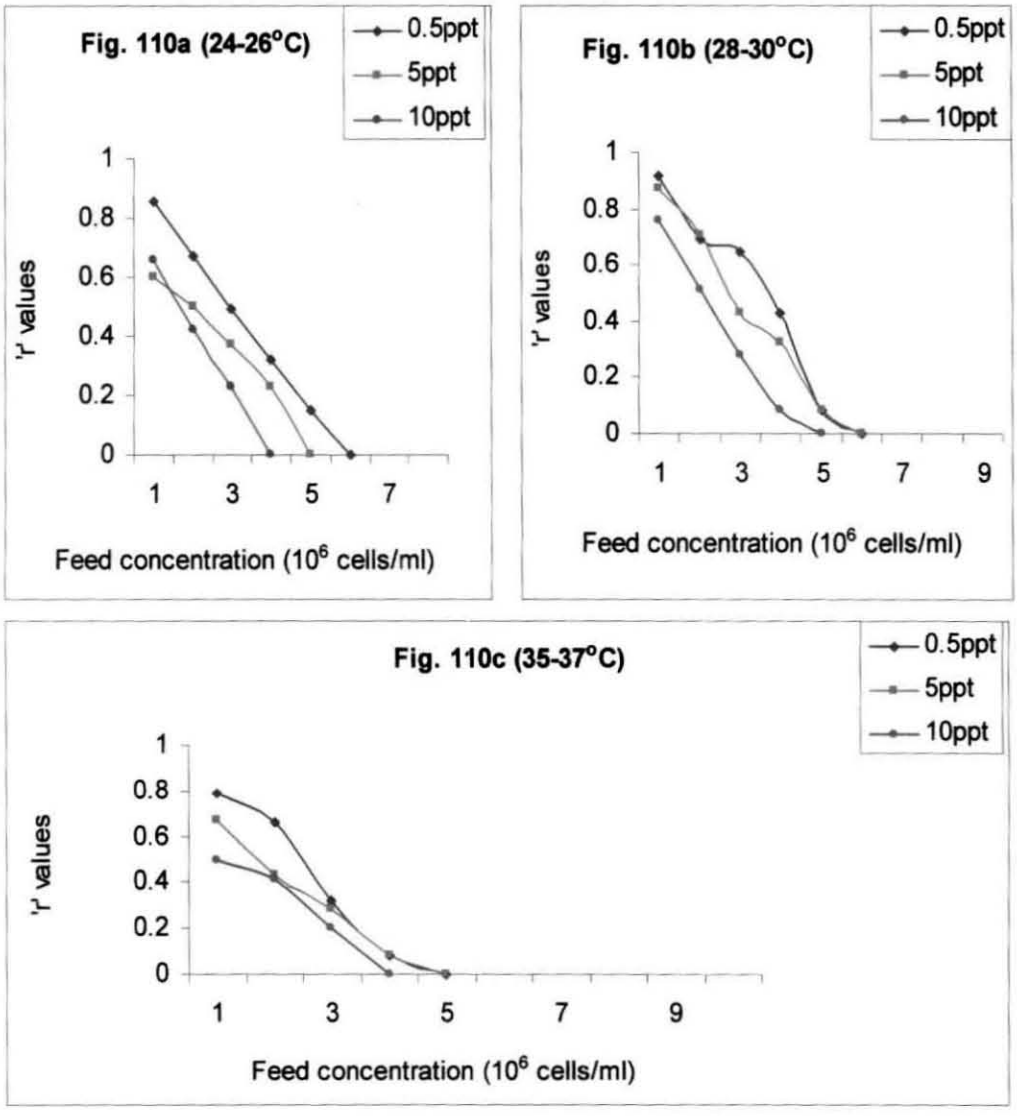


Table 18: Result of three-way ANOVA comparing the reproductive potential of *B. angularis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	118.39	2	297.68	14.58	0.00**
Feed concentration	2083.76	7	59.19	3.32	0.00**
Temperature	100.34	2	50.17	12.36	0.00**
Salinity x Feed concentration	179.82	14	12.85	3.16	0.00**
Feed concentration X Temperature	220.77	14	15.77	3.88	0.00**
Salinity x Temperature	18.07	4	4.65	1.15	0.348
Salinity X Feed concentration x Temp	82.07	28	2.93	0.72	0.843
Error	584.67	144	4.06		

(* p<0.05; **p<0.01)

Fig. 111a-c: Reproductive potential ('r') of *B. angularis* at different salinities and feed concentrations of *Chlorococcum infusorium* at three temperatures

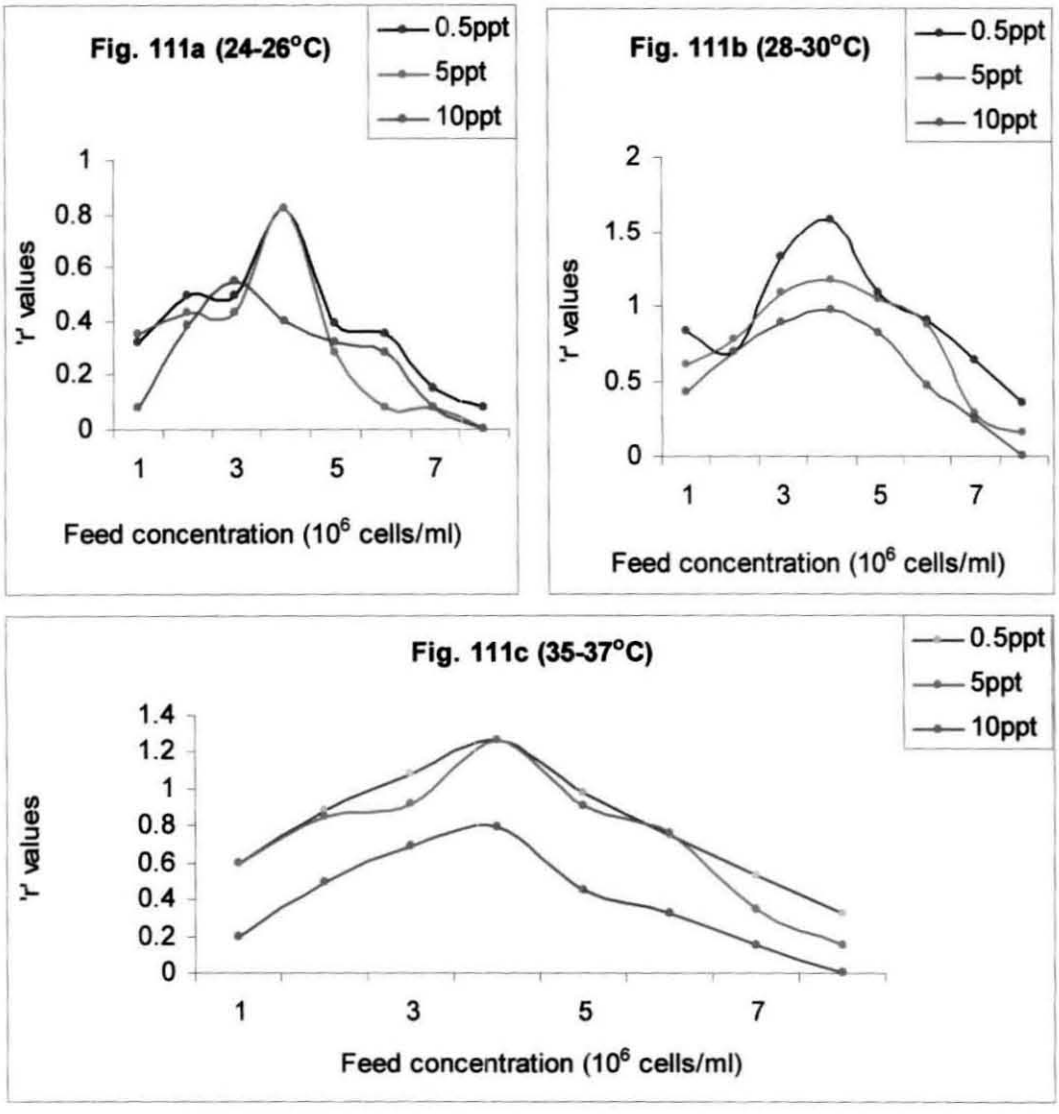
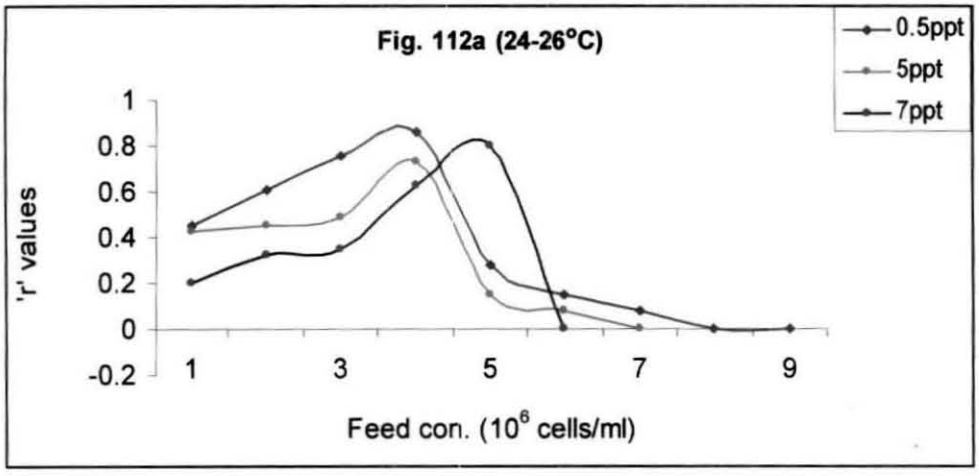


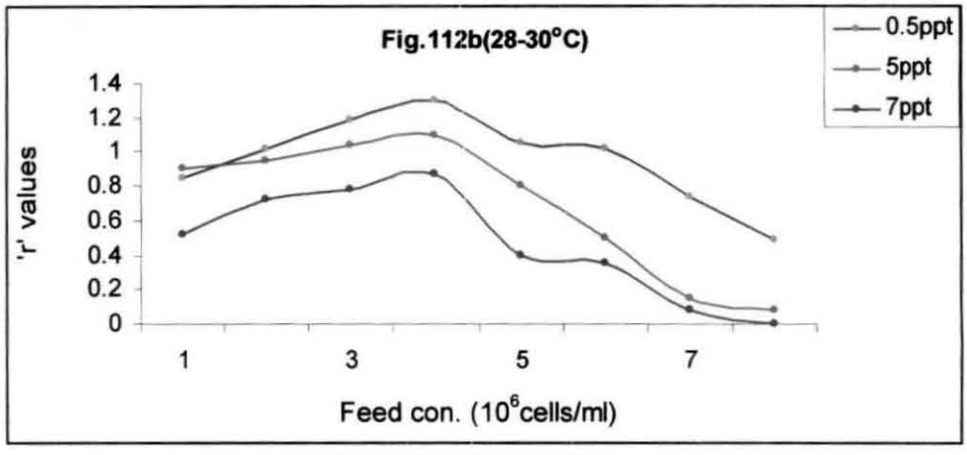
Table 19: Result of three-way ANOVA comparing the reproductive potential of *B. angularis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	5594.57	2	2797.28	87.86	0.00**
Feed concentration	19903.22	7	2843.32	89.31	0.00**
Temperature	7819.89	2	3909.95	122.81	0.00**
Salinity x Feed concentration	8033.44	14	573.82	18.02	0.00**
Feed concentration X Temperature	8672.55	14	619.47	19.46	0.00**
Salinity x Temperature	3343.19	4	835.79	26.25	0.00**
Salinity X Feed concentration x Temp	7146.59	28	255.24	8.02	0.00**
Error	4584.67	144	31.84		

(* $p<0.05$; **$p<0.01$)

Fig. 112a-c: Reproductive potential of *Brachionus caudatus* at different salinities and feed concentrations of *C. infusorium* at three temperatures





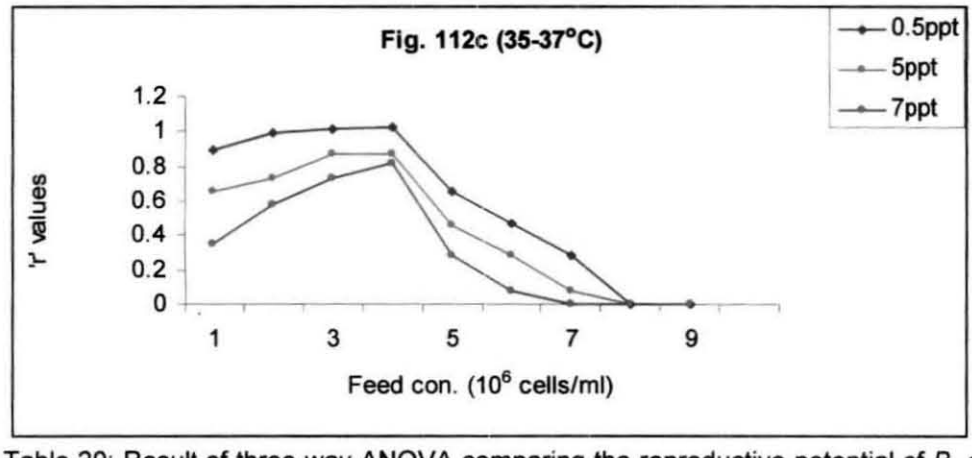


Table 20: Result of three-way ANOVA comparing the reproductive potential of *B. caudatus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	2674.75	2	1337.38	98.16	0.00**
Feed concentration	7628.65	7	1089.81	79.99	0.00**
Temperature	3585.19	2	1792.59	131.57	0.00**
Salinity x Feed concentration	1463.10	14	104.51	7.67	0.00**
Feed concentration X Temperature	2007.77	14	143.41	10.53	0.00**
Salinity x Temperature	1061.97	4	265.49	19.49	0.00**
Salinity X Feed concentration x Temp	874.39	28	31.23	2.29	0.01**
Error	1962.00	144	13.63		

(* $p<0.05$; ** $p<0.01$)

Fig.113a-c: Reproductive potential ('r') of *B. caudatus* at different salinities and feed concentrations of *S. protuberans* at three temperatures

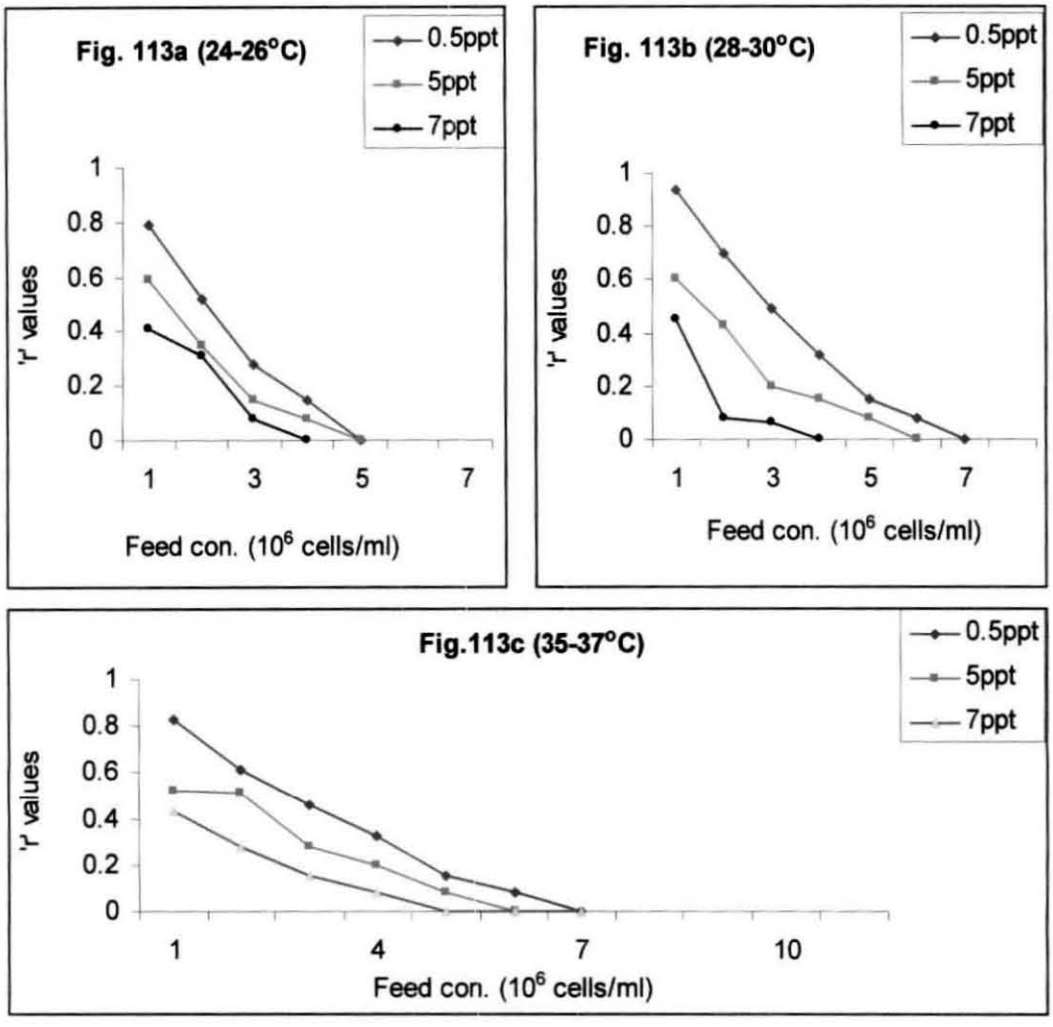


Table 21: Result of three-way ANOVA comparing the reproductive potential of *B. caudatus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	184.04	2	92.02	70.23	0.00**
Feed concentration	1189.54	7	169.93	129.70	0.00**
Temperature	14.51	2	7.26	5.34	0.00**
Salinity x Feed concentration	347.74	14	24.84	18.96	0.00**
Feed concentration x Temperature	14.82	14	1.06	0.81	0.659
Salinity x Temperature	24.96	4	6.24	4.76	0.01**
Salinity X Feed concentration x Temp	49.48	28	1.77	1.35	0.131
Error	188.67	144	1.31		

(* $p<0.05$; ** $p<0.01$)

Fig. 114a-c: Reproductive potential ('r') of *B. caudatus* at different salinities and feed concentrations of *C. ellipsoidea* at three temperatures

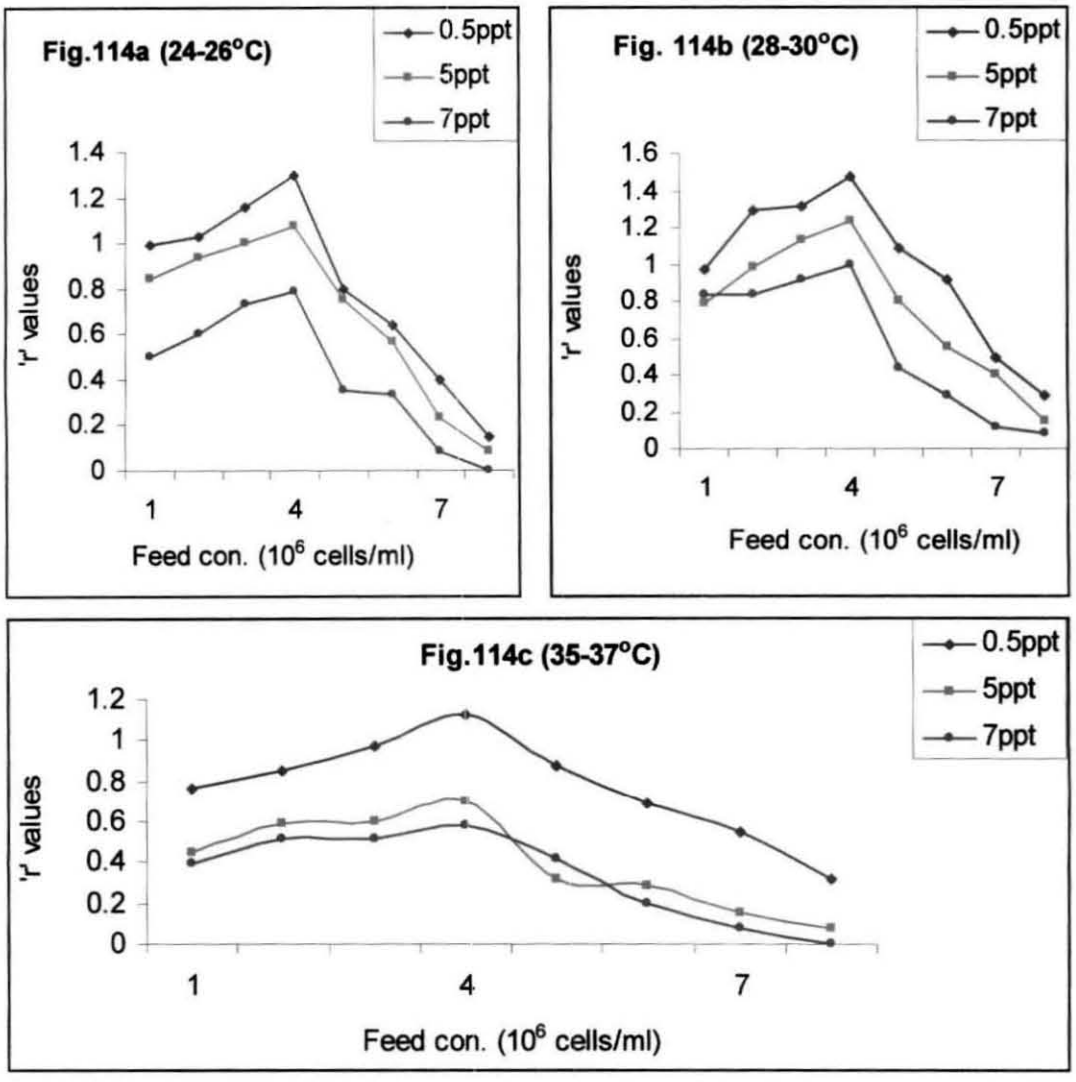


Table 22: Result of three-way ANOVA comparing the reproductive potential of *B. caudatus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	9352.39	2	4676.19	121.96	0.00**
Feed concentration	19363.17	7	2766.17	72.14	0.00**
Temperature	5372.07	2	2686.03	70.05	0.00**
Salinity x Feed concentration	6531.31	14	466.52	12.17	0.00**
Feed concentration x Temperature	4904.31	14	350.31	9.14	0.00**
Salinity x Temperature	1642.99	4	410.75	10.71	0.00**
Salinity x Feed concentration x Temp	1756.64	28	62.75	1.64	0.033
Error	5521.33	144	38.34		

(* $p<0.05$; ** $p<0.01$)

Fig.115a-c: Reproductive potential ('r') of *B. caudatus* at different salinities and feed concentrations of *A. convolutus* at three temperatures

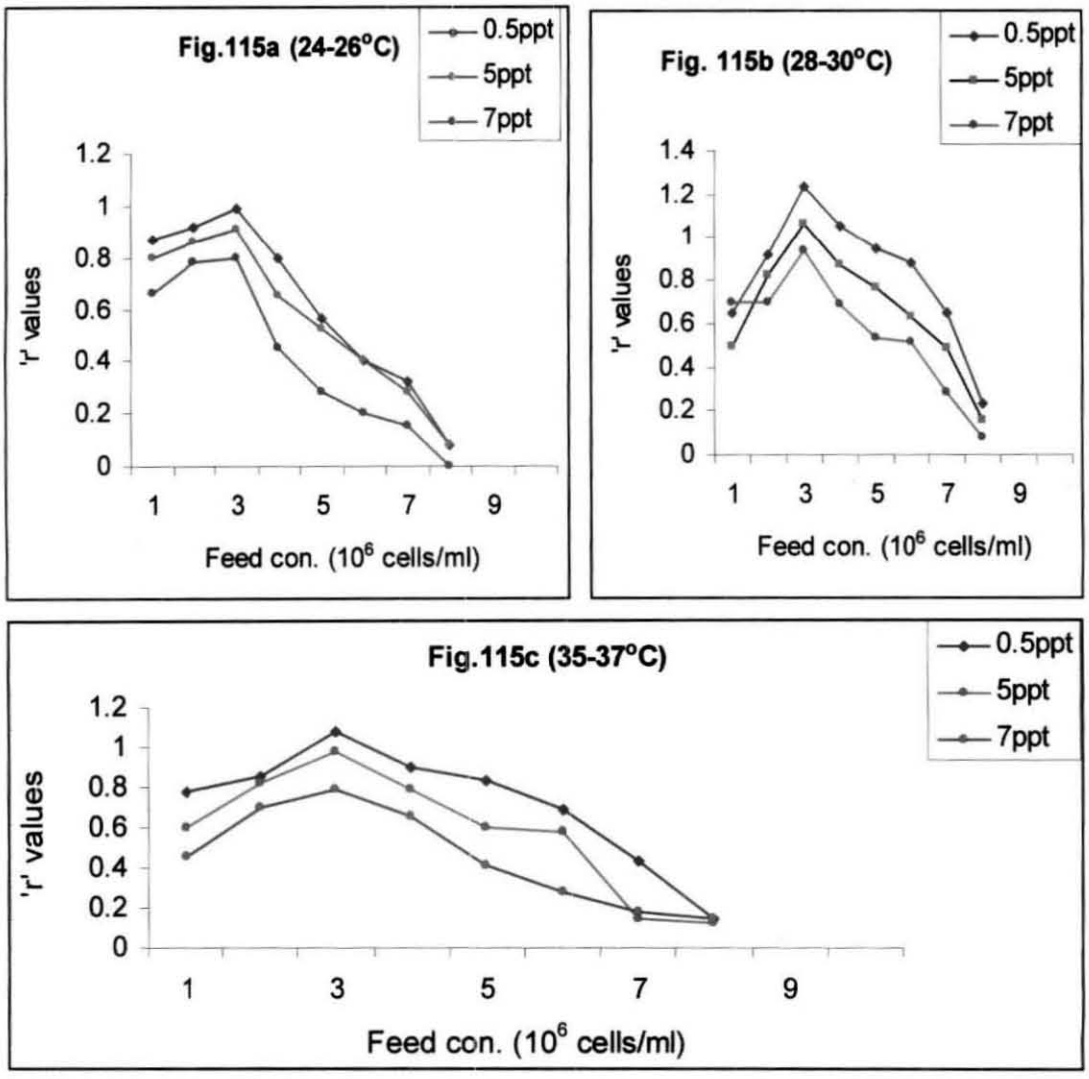


Table 23: Result of three-way ANOVA comparing the reproductive potential of *B. caudatus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	1450.01	2	725.01	90.52	0.00**
Feed concentration	6884.06	7	983.79	122.78	0.00**
Temperature	539.84	2	269.92	33.70	0.00**
Salinity x Feed concentration	767.03	14	54.79	6.84	0.00**
Feed concentration x Temperature	1032.97	14	73.78	9.21	0.00**
Salinity x Temperature	174.29	4	43.57	5.44	0.00**
Salinity x Feed concentration x Temp	451.78	28	16.14	2.02	0.04
Error	1153.33	144	8.01		

(* $p<0.05$; ** $p<0.01$)

Fig.116a-c: Reproductive potential ('r') of *Brachionus calyciflorus* at different salinities and feed concentrations of *C. ellipsoidea* at three temperatures

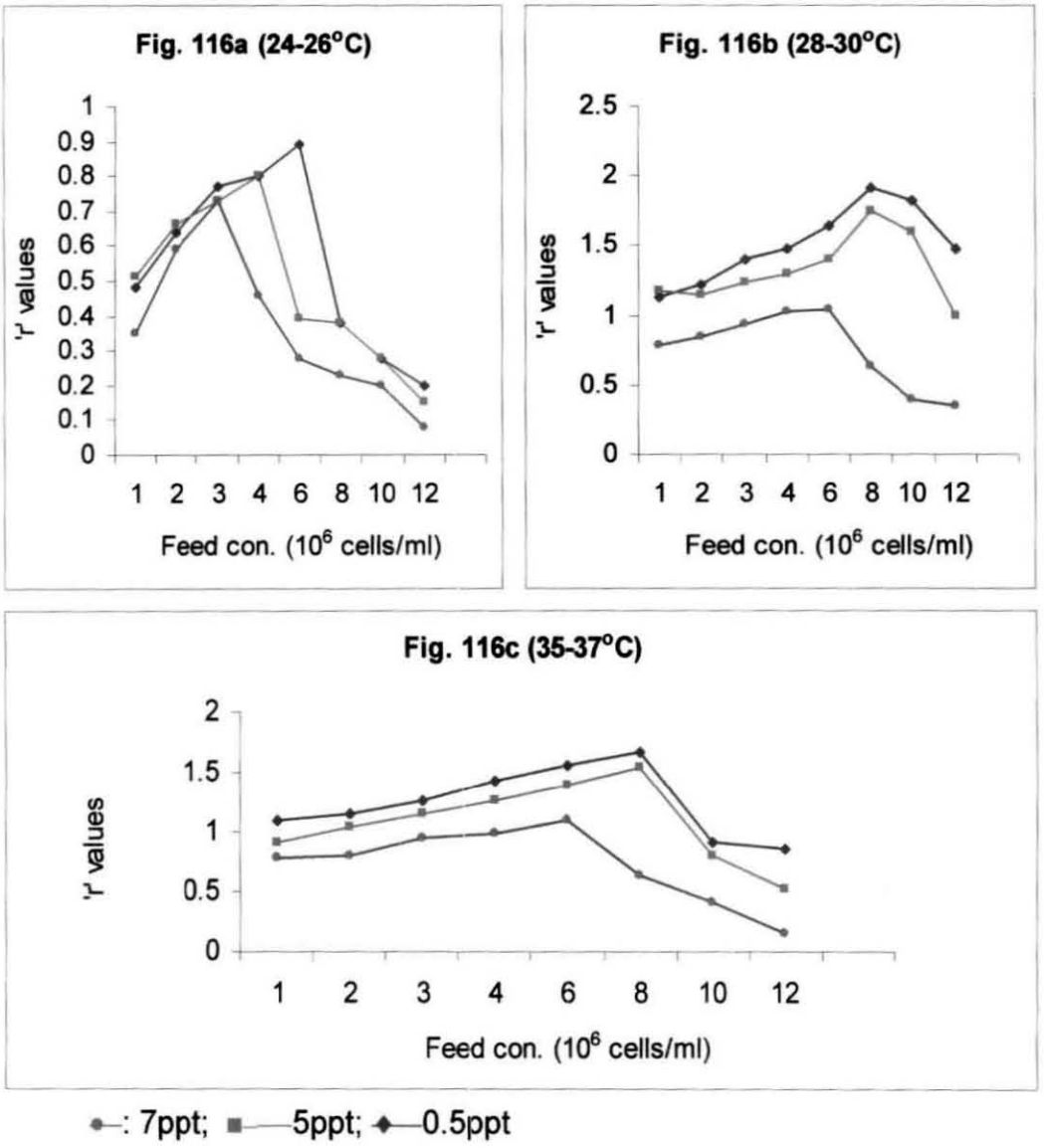


Table 24: Result of three-way ANOVA comparing the reproductive potential of *B. calyciflorus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	37867.93	2	5409.70	132.83	0.00**
Feed concentration	6368.12	7	3184.06	78.18	0.00**
Temperature	11091.95	2	5545.98	136.18	0.00**
Salinity x Feed concentration	15360.77	14	1097.19	26.94	0.00**
Feed concentration X Temperature	16072.05	14	1148.00	28.19	0.00**
Salinity x Temperature	2695.13	4	673.78	16.544	0.00**
Salinity X Feed concentration x Temp	1247.76	28	445.28	10.93	0.00**
Error	5864.67	144	40.73		

(* $p<0.05$; ** $p<0.01$)

Fig.117a-c: Reproductive potential ('r') of *B. calyciflorus* at different salinities and feed concentrations of *A. convolutus* at three temperatures

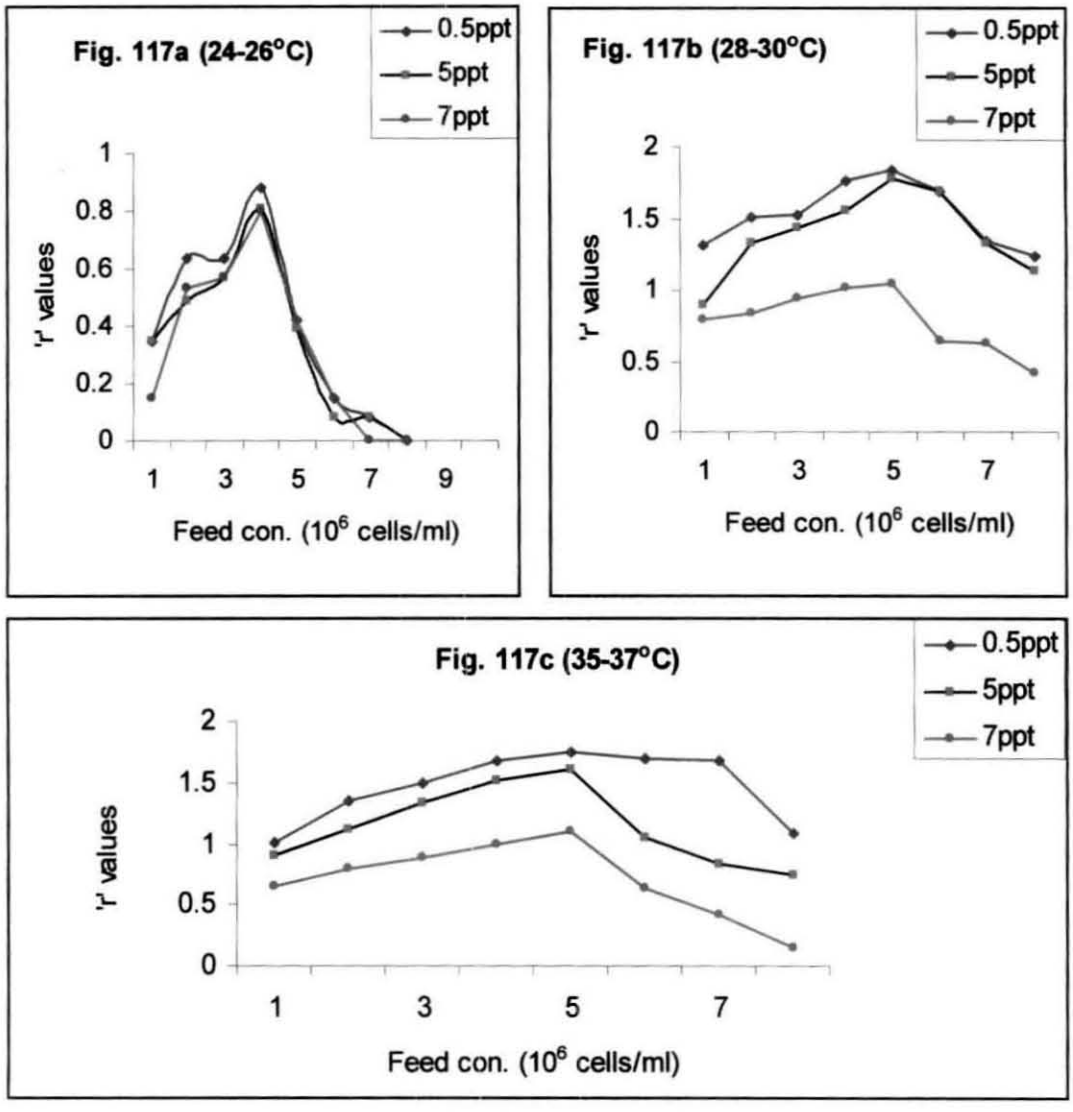


Table 25: Result of three-way ANOVA comparing the reproductive potential of *B. calyciflorus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	167684.07	2	23954.87	33.16	0.00**
Feed concentration	165509.62	7	82754.81	144.55	0.00**
Temperature	200164.57	2	100082.28	138.53	0.00**
Salinity x Feed concentration	91560.53	14	6540.04	9.05	0.00**
Feed concentration X Temperature	87371.36	14	6240.81	8.64	0.00**
Salinity x Temperature	86160.05	4	21540.01	29.82	0.00**
Salinity X Feed concentration x Temp	55732.92	28	1990.46	2.76	0.00**
Error	22184.67	144	154.06		

(* $p<0.05$; ** $p<0.01$)

Fig. 118a-c: Reproductive potential ('r') of *B. calyciflorus* at different salinities and feed concentrations of *S. protuberans* at three temperatures

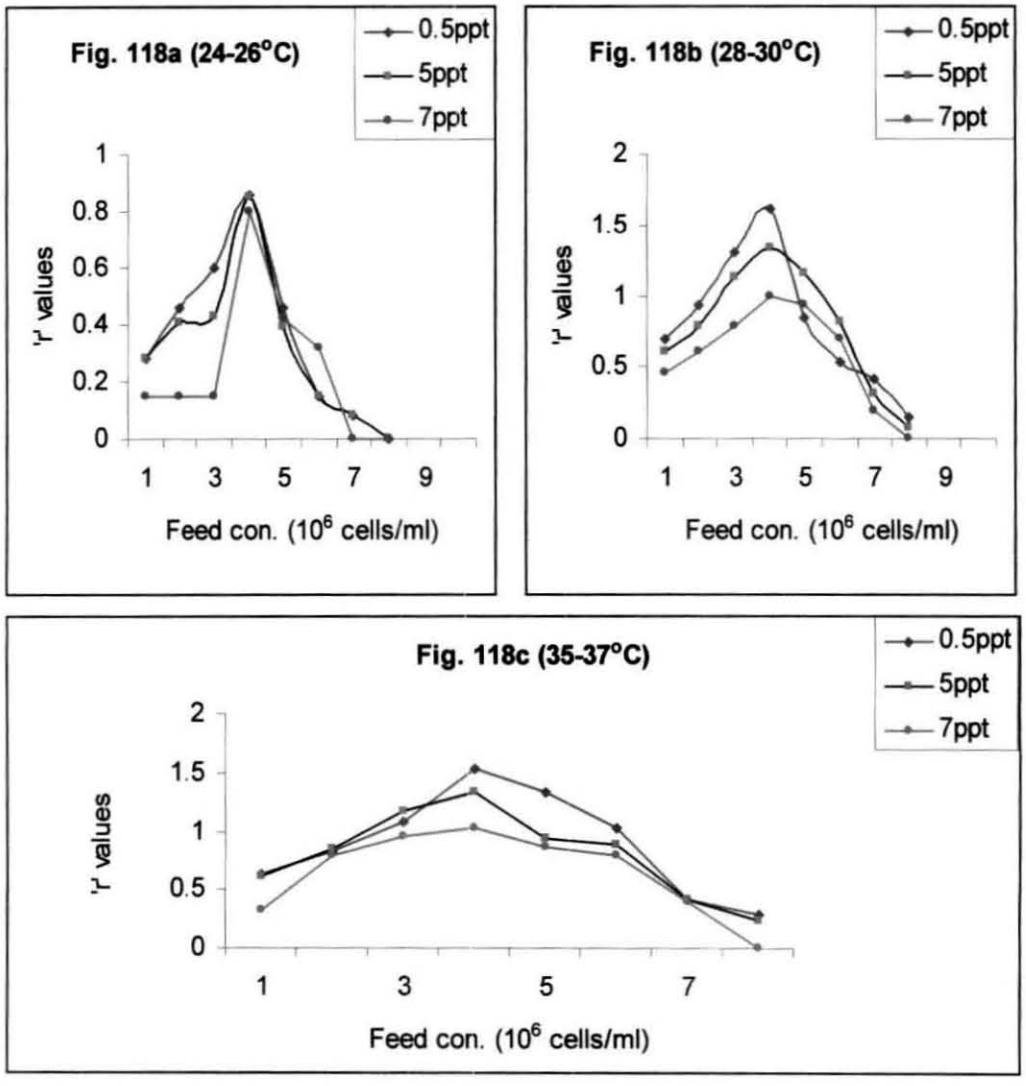
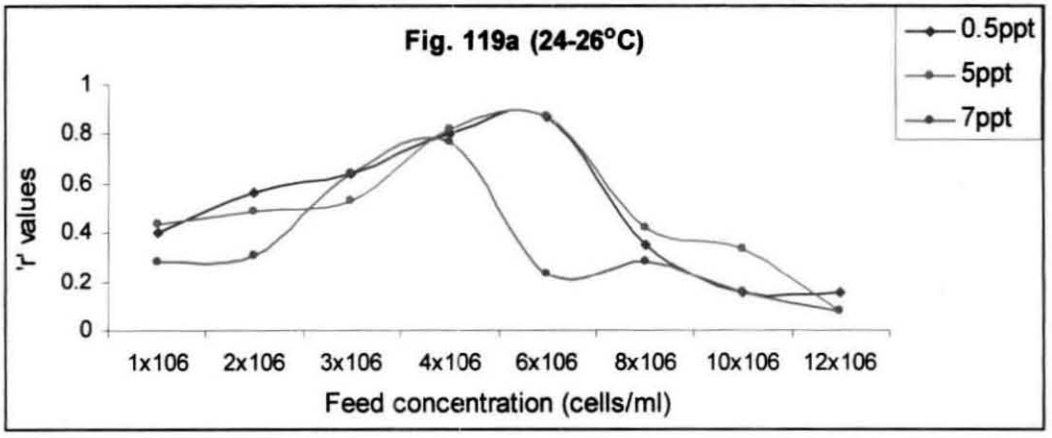


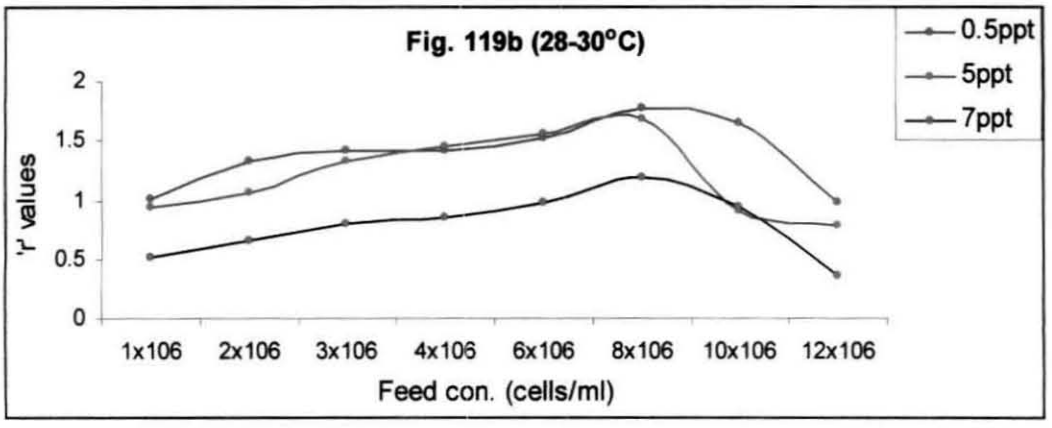
Table 26: Result of three-way ANOVA comparing the reproductive potential of *B. calyciflorus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	90301.33	2	12900.19	17.87	0.00**
Feed concentration	107813.69	7	53906.85	74.67	0.00**
Temperature	156999.19	2	78499.60	108.73	0.00**
Salinity x Feed concentration	66742.08	14	4767.29	6.60	0.00**
Feed concentration X Temperature	135977.25	14	9712.66	13.45	0.00**
Salinity x Temperature	79605.94	4	19901.49	27.57	0.00**
Salinity X Feed concentration x Temp	90847.833	28	3244.57	4.49	0.00**
Error	56307.34	144	154.06		

(* $p<0.05$; ** $p<0.01$)

Fig. 119a-c: Reproductive potential ('r') of *Brachionus calyciflorus* at different salinities and feed concentrations of *C. infusorium* at three temperatures





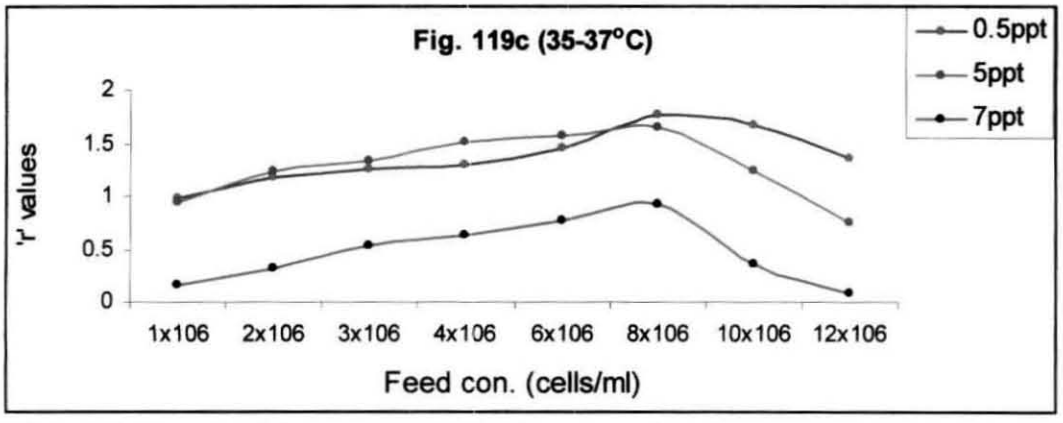


Table 27: Result of three-way ANOVA comparing the reproductive potential of *B. calyciflorus* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	114986.18	2	16426.59	76.05	0.00**
Feed concentration	93114.23	7	46557.12	215.56	0.00**
Temperature	101953.34	2	50976.67	236.02	0.00**
Salinity x Feed concentration	62637.69	14	4474.12	20.72	0.00**
Feed concentration X Temperature	62698.81	14	4478.49	20.74	0.00**
Salinity x Temperature	43728.38	4	10932.10	50.62	0.00**
Salinity X Feed concentration x Temp	36911.03	28	1318.25	6.10	0.00**
Error	31102.00	144	215.99		

(* p<0.05; **p<0.01)

Fig. 120a-c: Reproductive potential ('r) of *Brachionus plicatilis* at different feed concentration and salinities of *Tetraselmis gracilis* at three temperatures

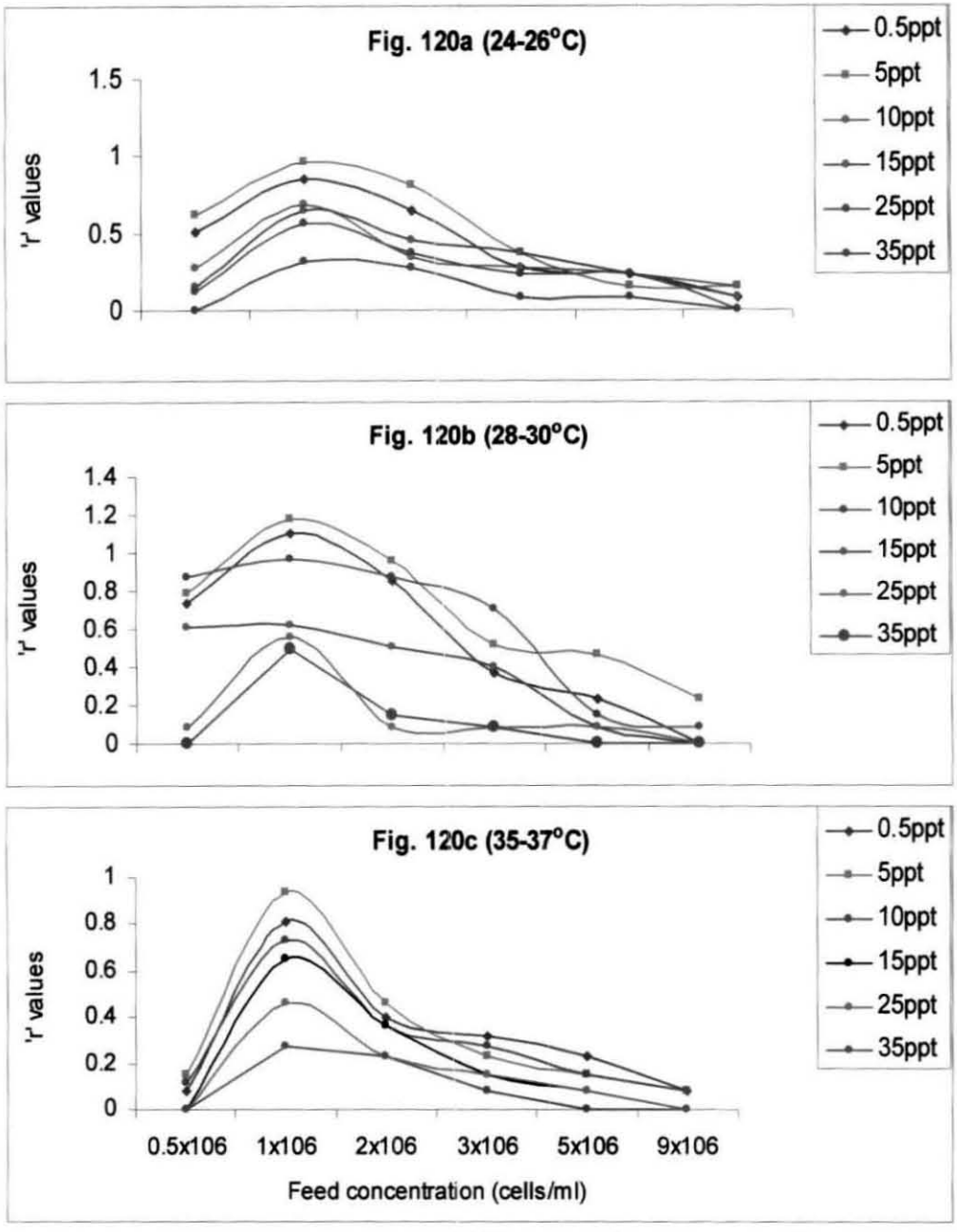
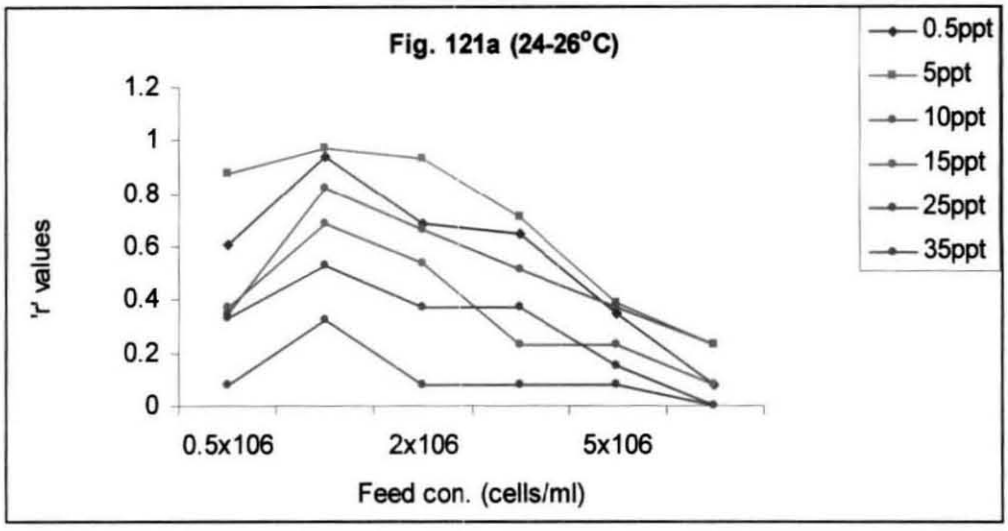


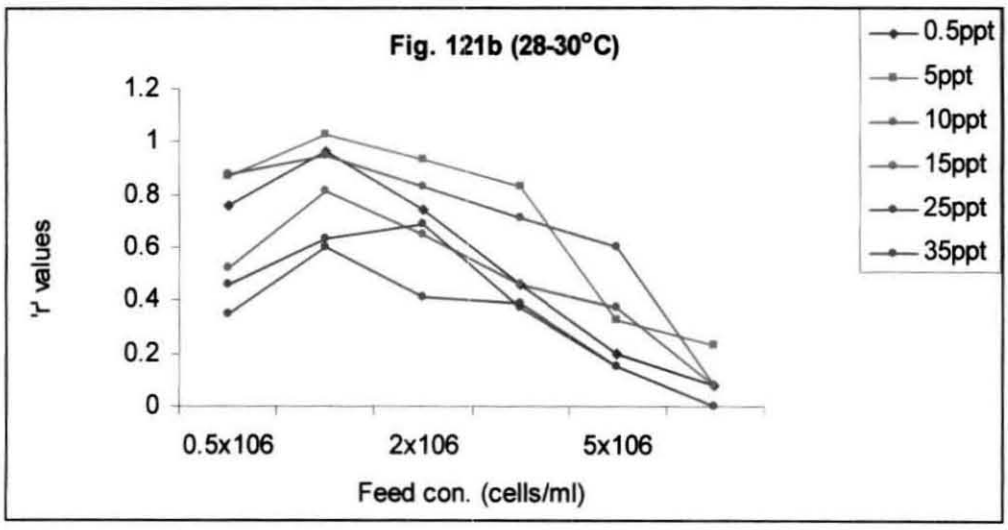
Table 28: Result of three-way ANOVA comparing the reproductive potential of *B. plicatilis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	1524.14	5	306.83	222.39	0.00**
Feed concentration	3448.14	5	689.63	499.86	0.00**
Temperature	885.39	2	442.69	320.88	0.00**
Salinity x Feed concentration	1888.69	25	75.55	54.76	0.00**
Feed concentration X Temperature	721.72	10	72.17	52.31	0.00**
Salinity x Temperature	699.17	10	69.92	50.68	0.00**
Salinity X Feed concentration x Temp	797.72	50	15.95	11.56	0.00**
Error	298.00	216	1.38		

(* $p<0.05$; **$p<0.01$)

Fig. 121a-c: Reproductive potential ('r') of *B. plicatilis* at different salinities and feed concentrations of *Chaetoceros calcitrans* at three temperatures





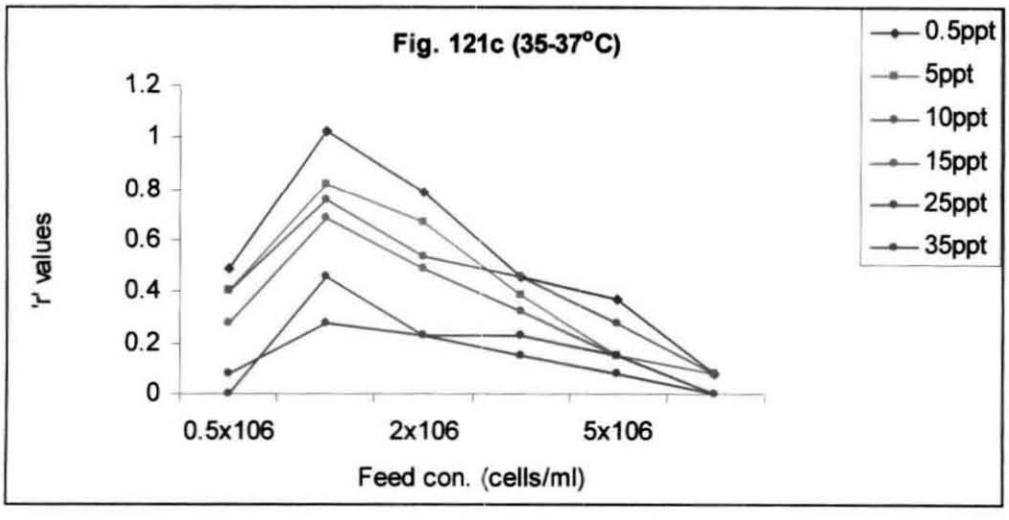
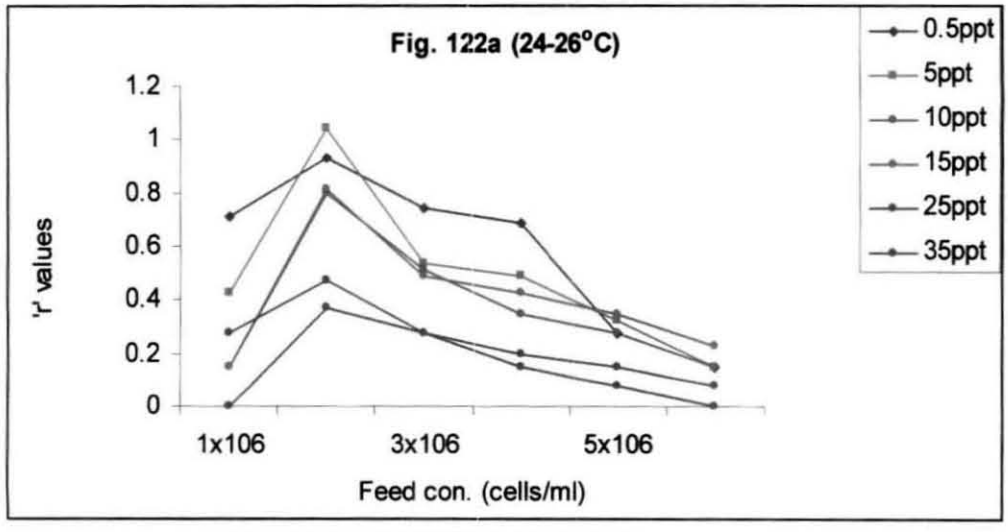


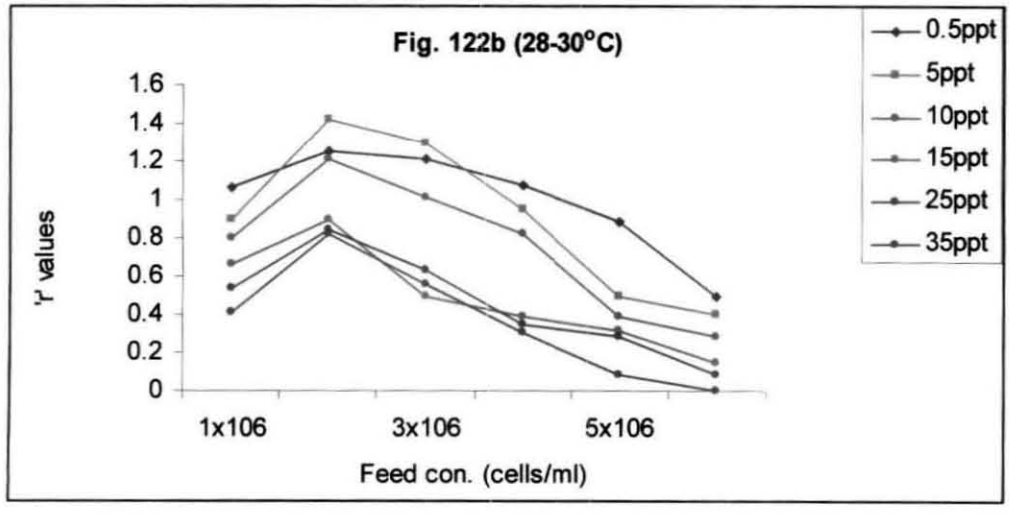
Table 29: Result of three-way ANOVA comparing the reproductive potential of *B. plicatilis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	1680.99	5	336.20	295.20	0.00**
Feed concentration	2884.51	5	576.55	506.55	0.00**
Temperature	289.57	2	144.79	127.13	0.00**
Salinity x Feed concentration	830.14	25	33.21	29.16	0.00**
Feed con. x Temperature	482.61	10	48.26	42.38	0.00**
Salinity x Temperature	381.57	10	38.16	33.50	0.00**
Salinity x Feed con. x Temp	669.57	50	13.39	11.76	0.00**
Error	246.00	216	1.14		

(* $p<0.05$; **$p<0.01$)

Fig.122a-c: Reproductive potential ('r') of *B. plicatilis* at different salinities and feed concentrations of *Isocrysis galbana* at three temperatures





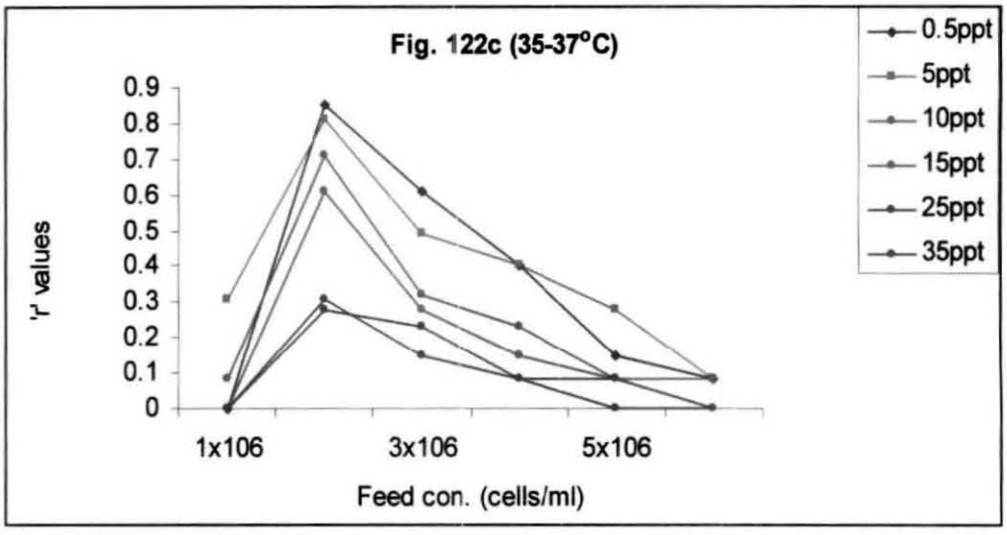
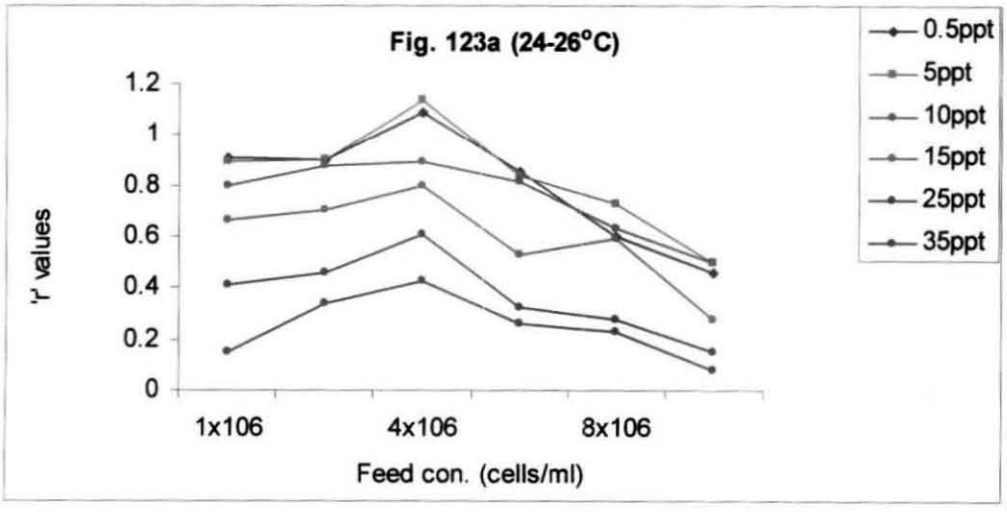


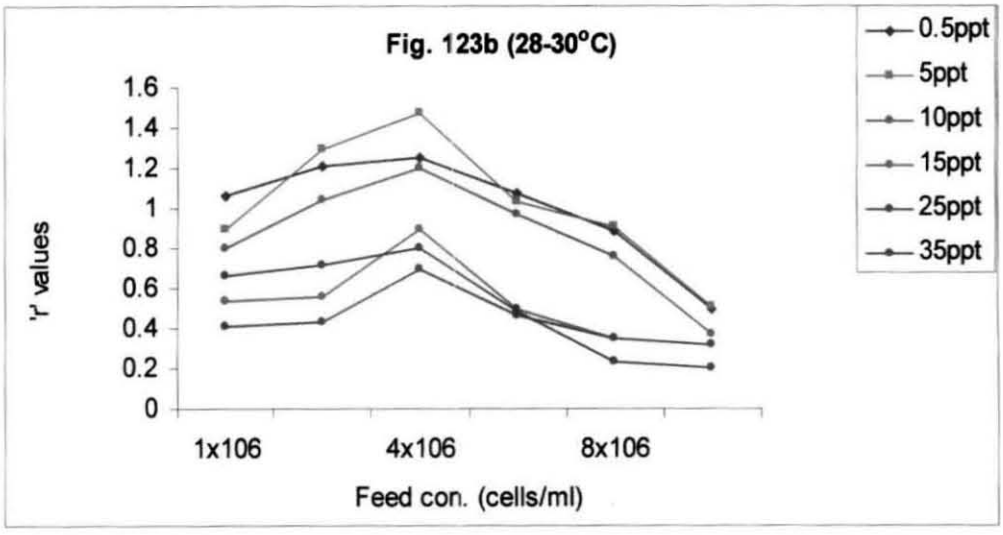
Table 30: Result of three-way ANOVA comparing the reproductive potential of *B. plicatilis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	4840.09	5	968.02	149.49	0.00**
Feed concentration	7893.68	5	1578.74	243.81	0.00**
Temperature	8007.90	2	4003.95	618.34	0.00**
Salinity x Feed concentration	4415.45	25	176.62	27.28	0.00**
Feed con. x Temperature	4945.59	10	494.56	76.38	0.00**
Salinity x Temperature	4410.74	10	441.07	68.12	0.00**
Salinity x Feed con. x Temp	3795.78	50	75.92	11.72	0.00**
Error	1398.67	216	6.48		

(* $p<0.05$; ** $p<0.01$)

Fig. 123a-c: Reproductive potential ('r') of *B. plicatilis* at different salinities and feed concentrations of *C. infusorium* at three temperatures





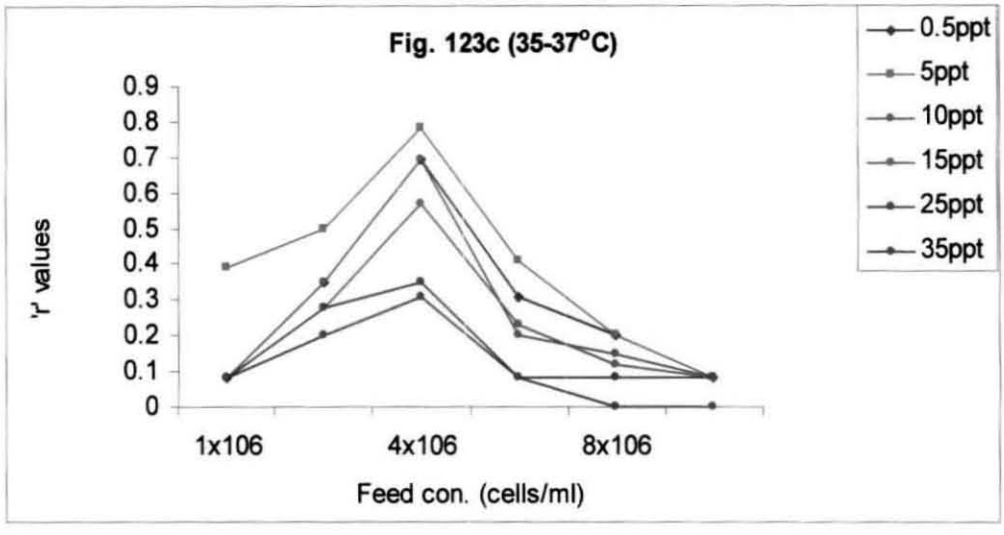
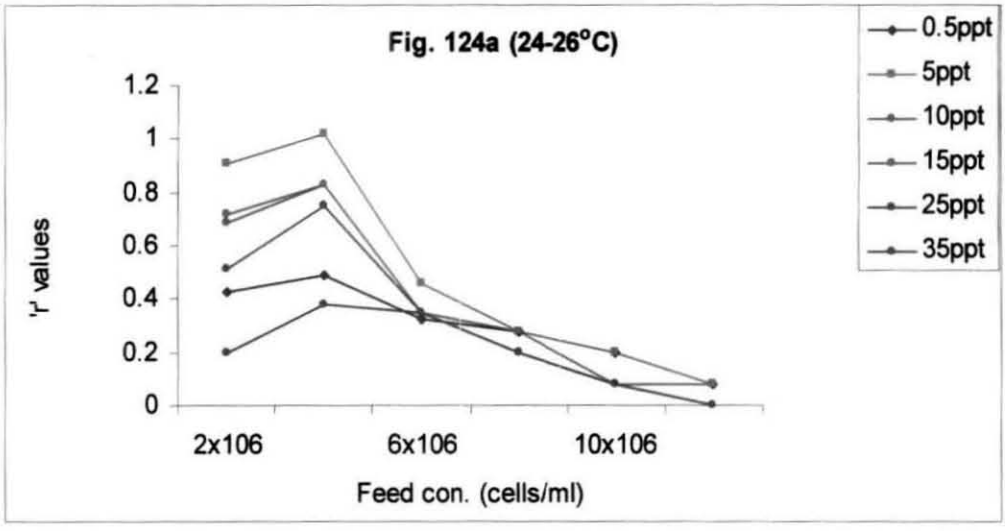


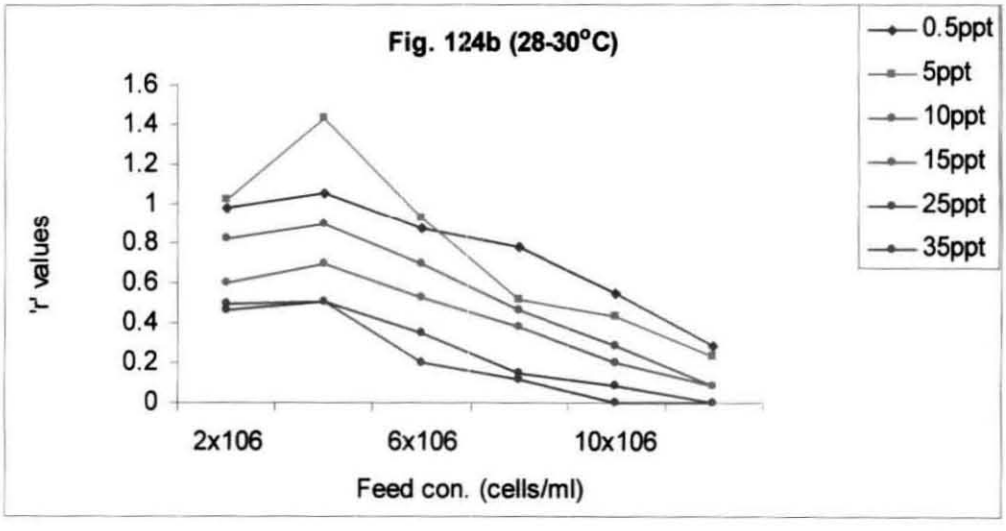
Table 31: Result of three-way ANOVA comparing the reproductive potential of *B. plicatilis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	8481.02	5	1696.20	172.98	0.00**
Feed concentration	6660.90	5	1332.18	135.86	0.00**
Temperature	7777.78	2	3888.89	396.60	0.00**
Salinity x Feed concentration	4538.26	25	181.53	18.51	0.00**
Feed con. x Temperature	3348.33	10	334.83	34.15	0.00**
Salinity x Temperature	4867.22	10	486.72	49.64	0.00**
Salinity x Feed con. x Temp	3994.23	50	79.89	8.15	0.00**
Error	2118.00	216	9.81		

(* $p<0.05$; ** $p<0.01$)

Fig. 124a-c: Reproductive potential ('r') of *B. plicatilis* at different salinities and feed concentrations of *Chlorella salina* at three temperatures





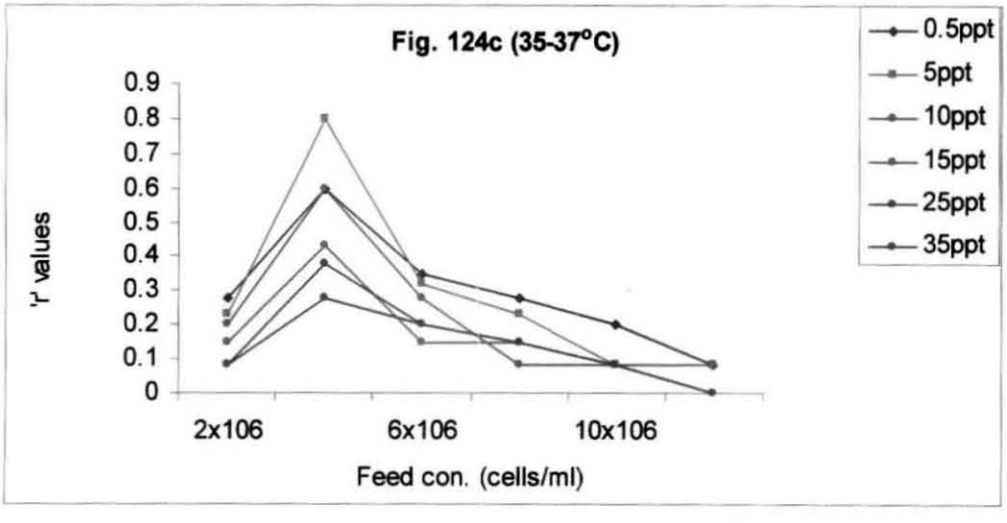
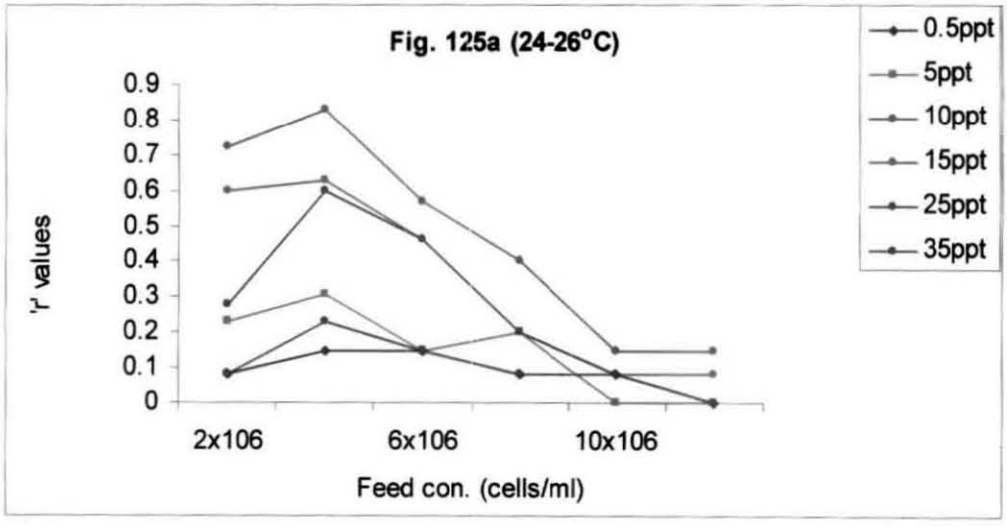


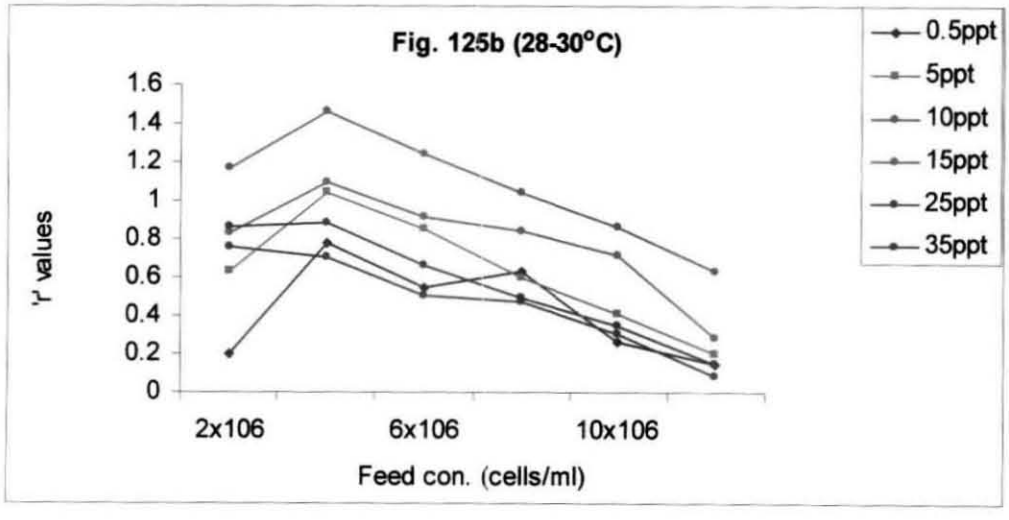
Table 32: Result of three-way ANOVA comparing the reproductive potential of *B. plicatilis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	2646.77	5	529.35	48.37	0.00**
Feed concentration	4859.73	5	971.95	88.81	0.00**
Temperature	2567.80	2	1283.90	117.31	0.00**
Salinity x Feed concentration	5080.49	25	203.22	18.57	0.00**
Feed con. x Temperature	2944.35	10	294.44	26.90	0.00**
Salinity x Temperature	2795.42	10	279.54	25.54	0.00**
Salinity x Feed con. x Temp	7108.21	50	142.16	12.99	0.00**
Error	2364.00	216	10.94		

(* $p<0.05$; **$p<0.01$)

Fig. 125a-c: Reproductive potential ('r') of *Brachionus murray* at different salinities and feed concentrations of *C. salina* at three temperatures





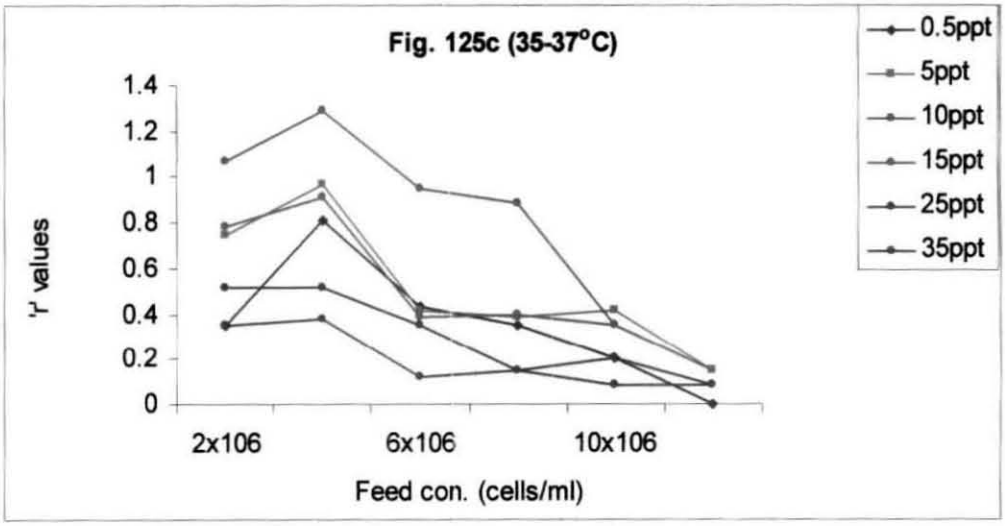
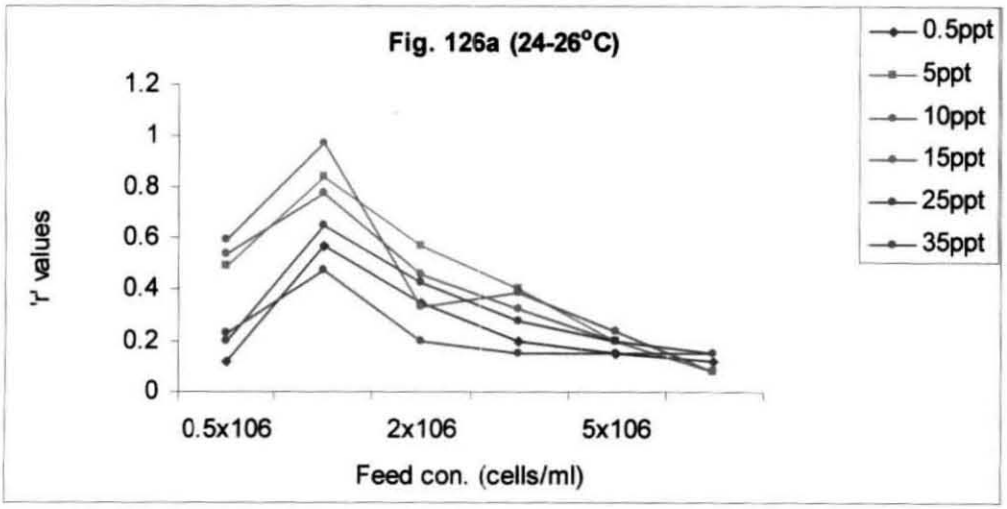


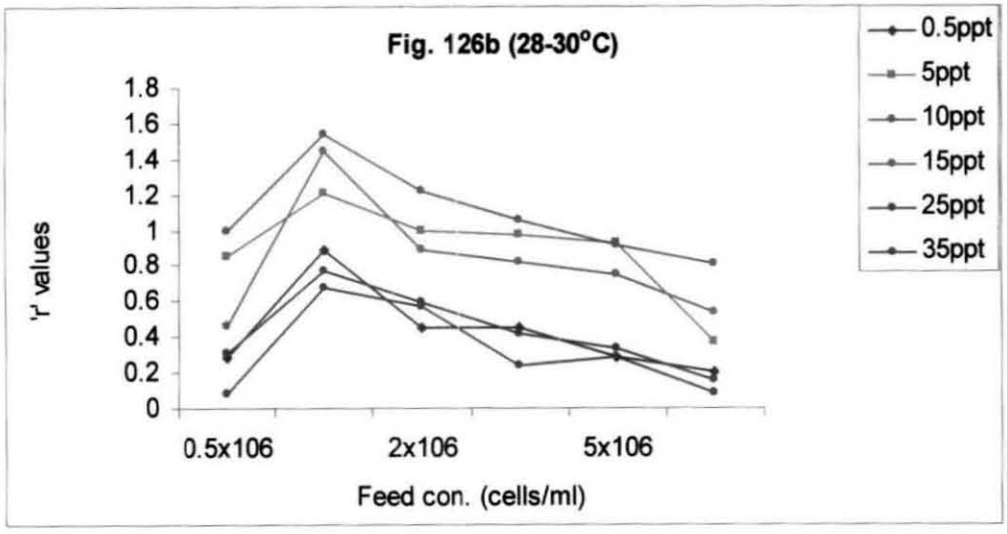
Table 33: Result of three-way ANOVA comparing the reproductive potential of *B. murray* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	10809.35	5	2161.87	17.66	0.00**
Feed concentration	7151.87	5	1430.37	116.88	0.00**
Temperature	5136.78	2	2568.39	209.88	0.00**
Salinity x Feed concentration	5541.56	25	221.66	18.11	0.00**
Feed con. x Temperature	3050.29	10	305.03	24.93	0.00**
Salinity x Temperature	4011.92	10	401.19	32.78	0.00**
Salinity x Feed con. x Temp	2999.67	50	99.99	4.90	0.00**
Error	2643.33	216	12.24		

(* $p<0.05$; ** $p<0.01$)

Fig. 126a-c: Reproductive potential ('r') of *B. murray* at different salinities and feed concentrations of *Tetraselmis gracilis* at three temperatures





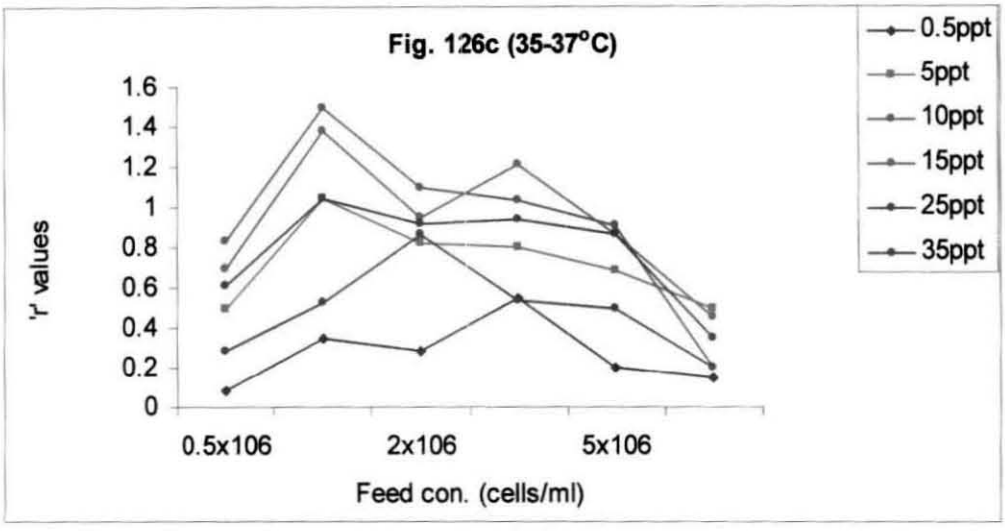
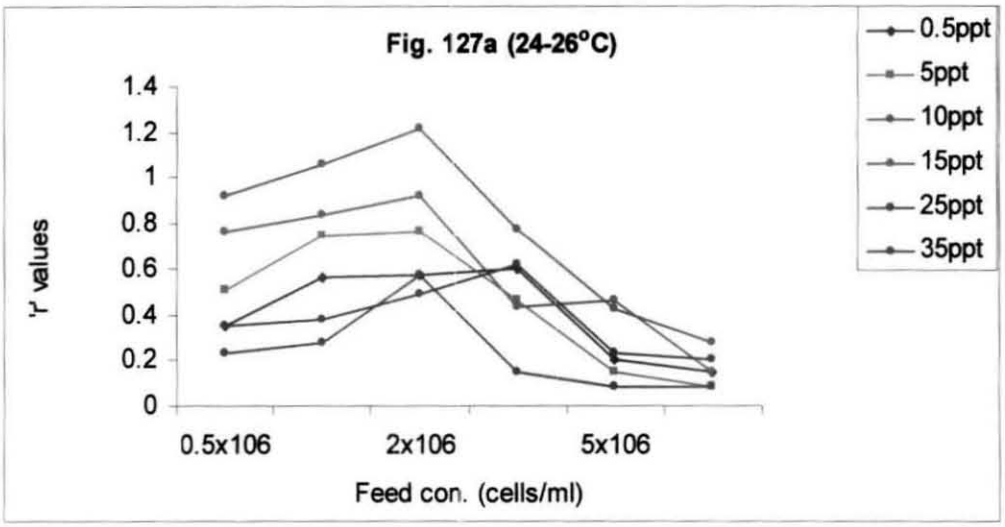


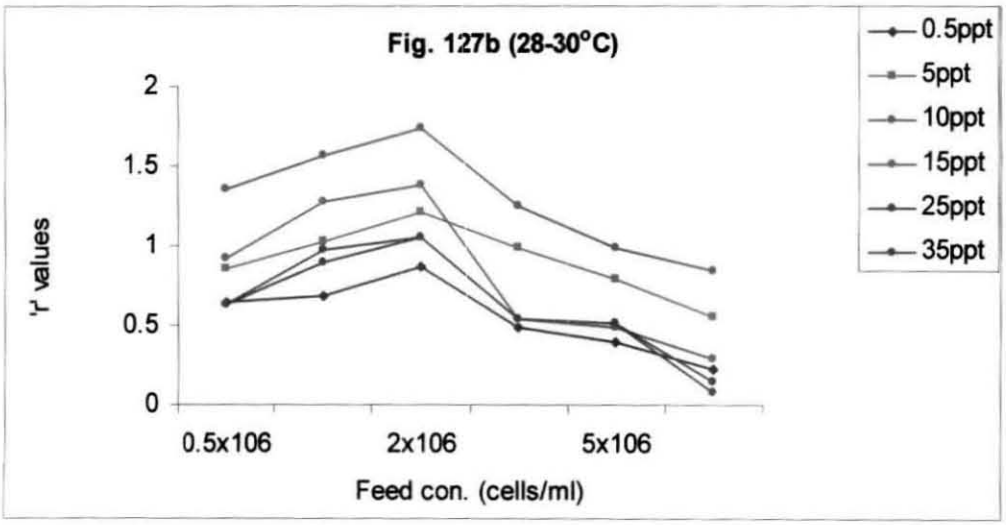
Table 34: Result of three-way ANOVA comparing the reproductive potential of *B. murray* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	14728.99	5	2945.79	70.97	0.00**
Feed concentration	15223.62	5	3044.72	73.35	0.00**
Temperature	8761.19	2	4380.59	105.53	0.00**
Salinity x Feed concentration	10902.81	25	436.11	10.51	0.00**
Feed con. x Temperature	14486.00	10	1448.60	34.90	0.00**
Salinity x Temperature	6948.41	10	694.84	16.74	0.00**
Salinity x Feed con. x Temp	12511.74	50	250.24	6.03	0.00**
Error	8966.00	216	41.51		

(* $p<0.05$; ** $p<0.01$)

Fig. 127a-c: Reproductive potential ('r') of *B. murray* at different salinities and feed concentrations of *C. calcitrans* at three temperatures





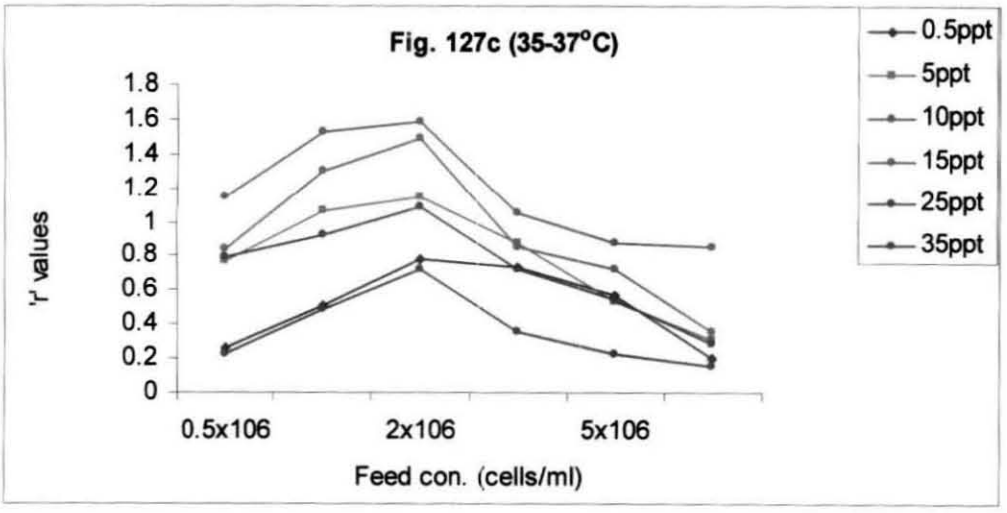
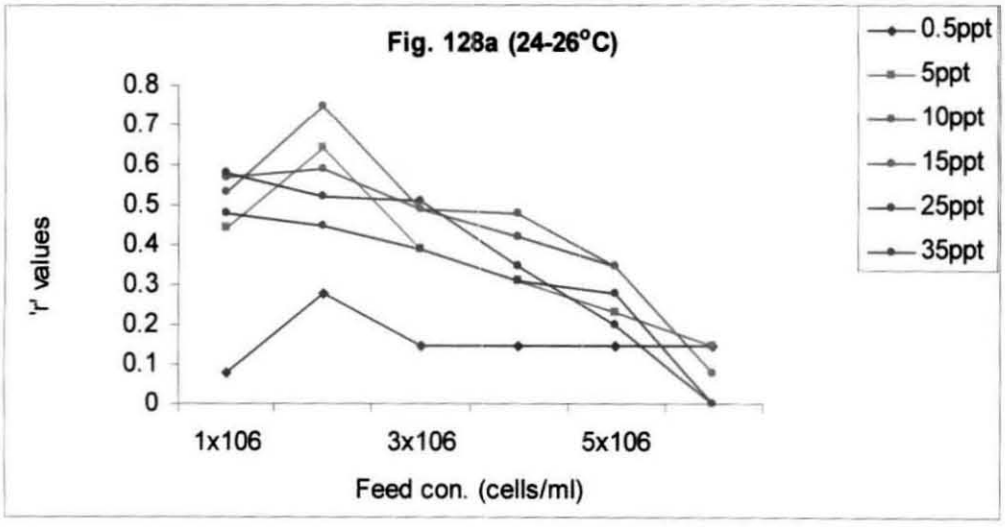


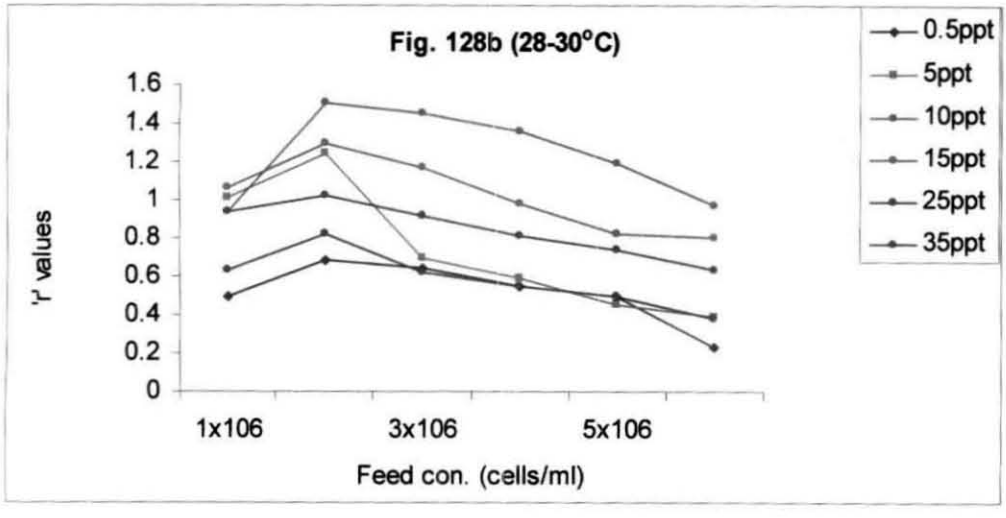
Table 35: Result of three-way ANOVA comparing the reproductive potential of *B. murray* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	72916.98	5	14583.40	73.98	0.00**
Feed concentration	45530.98	5	9106.10	45.98	0.00**
Temperature	16878.71	2	8439.36	52.62	0.00**
Salinity x Feed concentration	59606.71	25	2384.36	12.04	0.00**
Feed con. x Temperature	15663.36	10	1566.34	7.91	0.00**
Salinity x Temperature	21892.22	10	2189.22	11.06	0.00**
Salinity x Feed con. x Temp	26706.82	50	534.14	2.70	0.00**
Error	42774.67	216	198.03		

(* $p<0.05$; **$p<0.01$)

Fig. 128a-c: Reproductive potential ('r') of *B. murray* at different salinities and feed concentrations of *Isocrysis galbana* at three temperatures





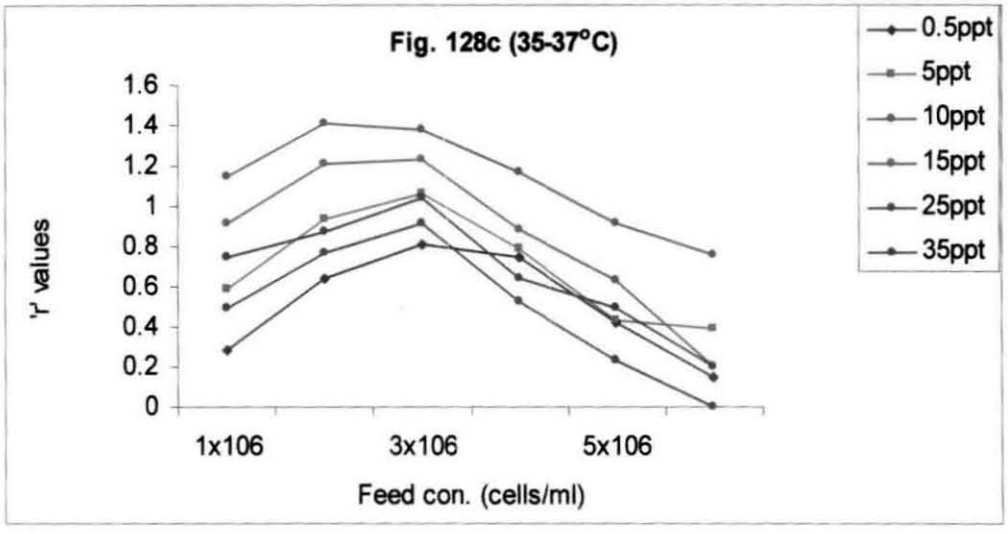
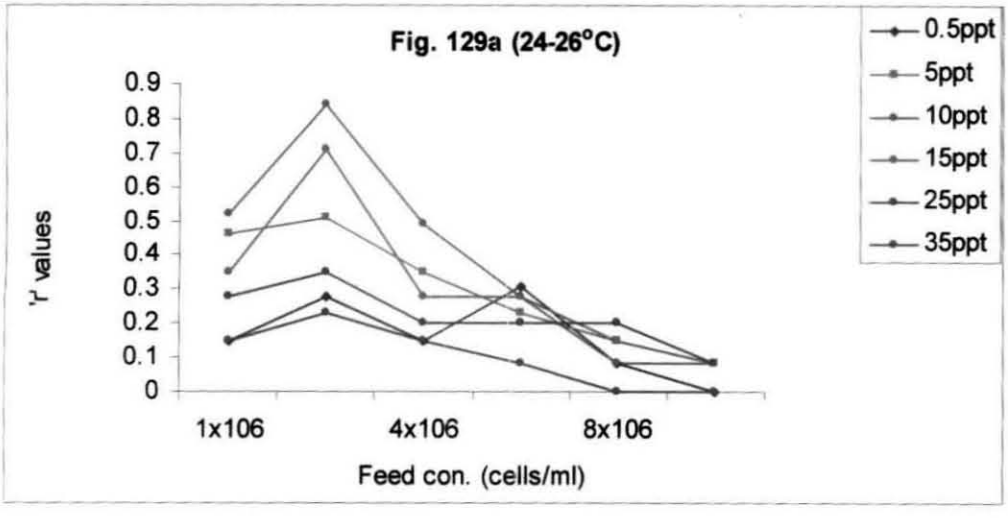


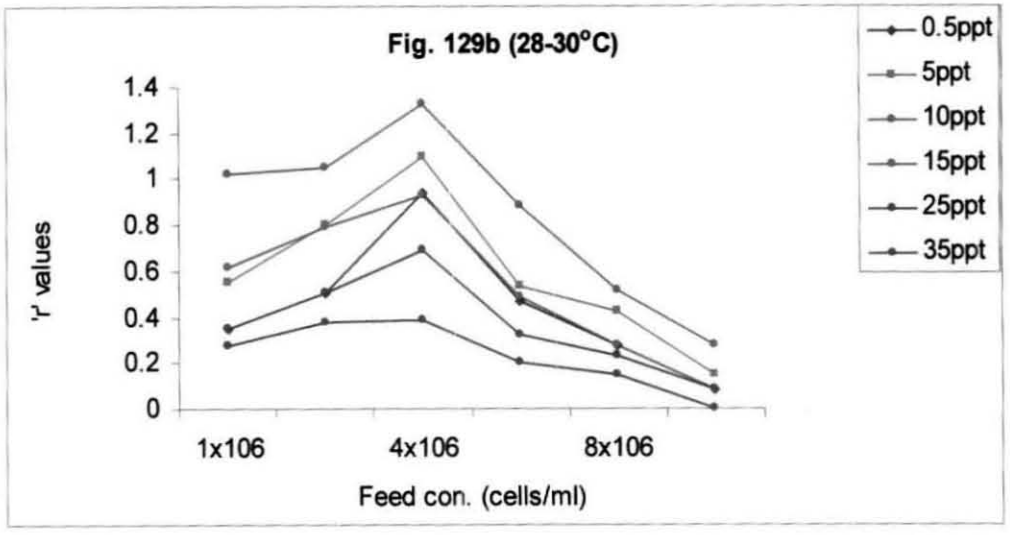
Table 36: Result of three-way ANOVA comparing the reproductive potential of *B. murray* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	24292.83	5	4858.57	117.06	0.00**
Feed concentration	14783.98	5	2956.80	71.24	0.00**
Temperature	15818.23	2	7909.11	190.55	0.00**
Salinity x Feed concentration	9455.15	25	378.21	9.11	0.00**
Feed con. x Temperature	6798.70	10	679.87	16.38	0.00**
Salinity x Temperature	12587.07	10	1258.71	30.33	0.00**
Salinity x Feed con. x Temp	10764.67	50	215.29	5.19	0.00**
Error	8965.33	216	41.51		

(* $p<0.05$; ** $p<0.01$)

Fig. 129a-c: Reproductive potential ('r') of *B. murray* at different salinities and feed concentrations of *Chlorococcum infusorium* at three temperatures





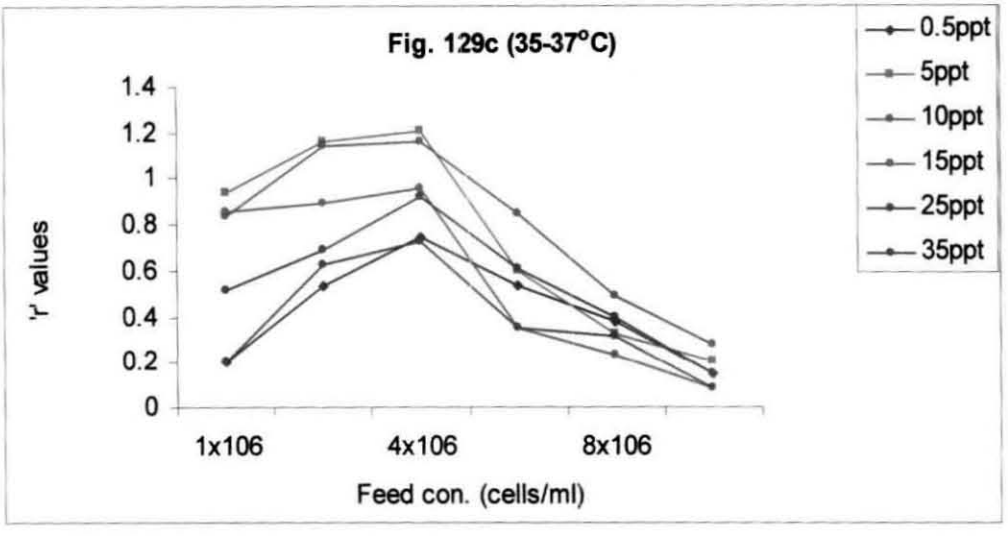
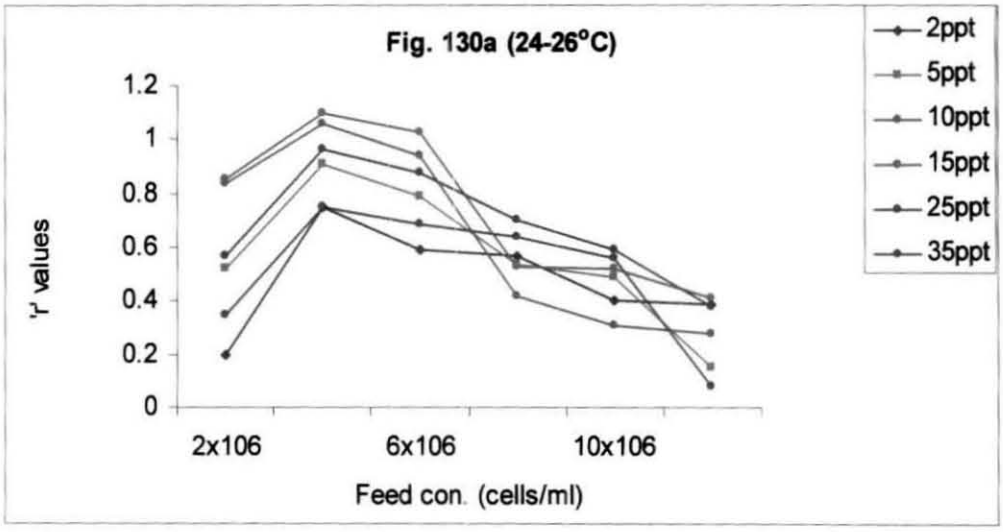


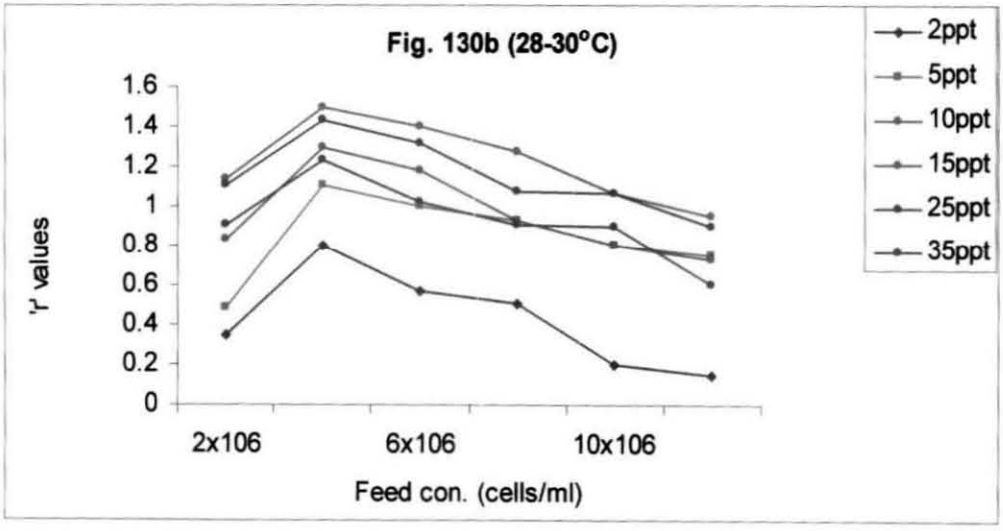
Table 37: Result of three-way ANOVA comparing the reproductive potential of *B. murray* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	6513.90	5	1302.78	23.38	0.00**
Feed concentration	4653.39	5	930.68	16.71	0.00**
Temperature	2063.38	2	1031.69	18.52	0.00**
Salinity x Feed concentration	2623.71	25	104.95	1.88	0.09
Feed con. x Temperature	4355.40	10	435.54	7.82	0.00**
Salinity x Temperature	1615.33	10	161.53	2.90	0.00**
Salinity x Feed con. x Temp	6716.56	50	134.33	2.41	0.00**
Error	12034.00	216	55.71		

(* $p<0.05$; **$p<0.01$)

Fig. 130a-c: Reproductive potential ('r) of *Brachionus rotundiformis* at different salinities and feed concentrations of *Chlorella salina* at three temperatures





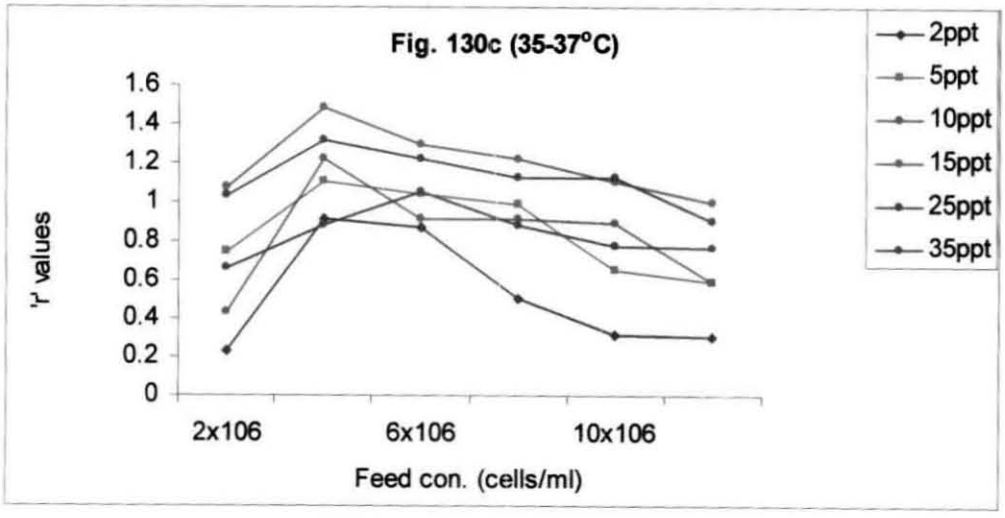
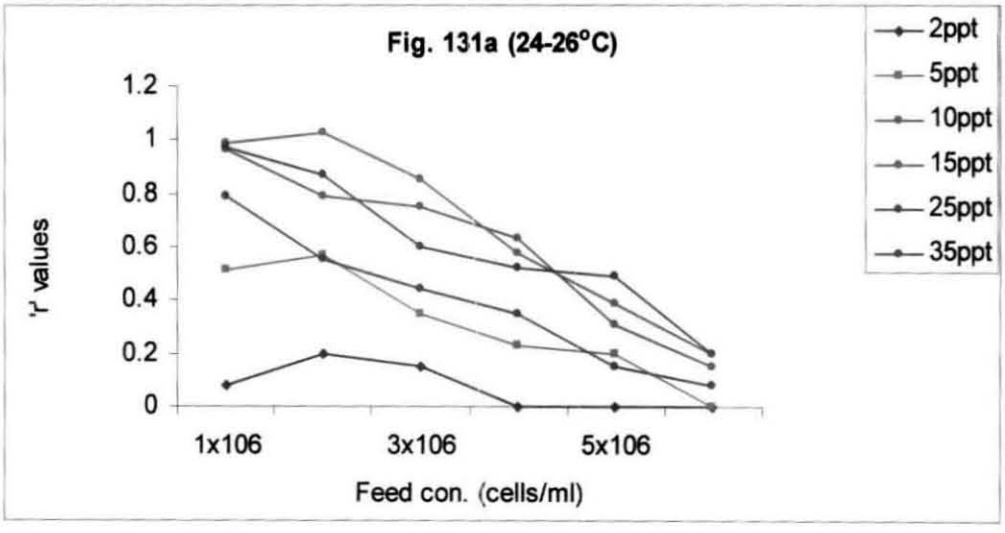


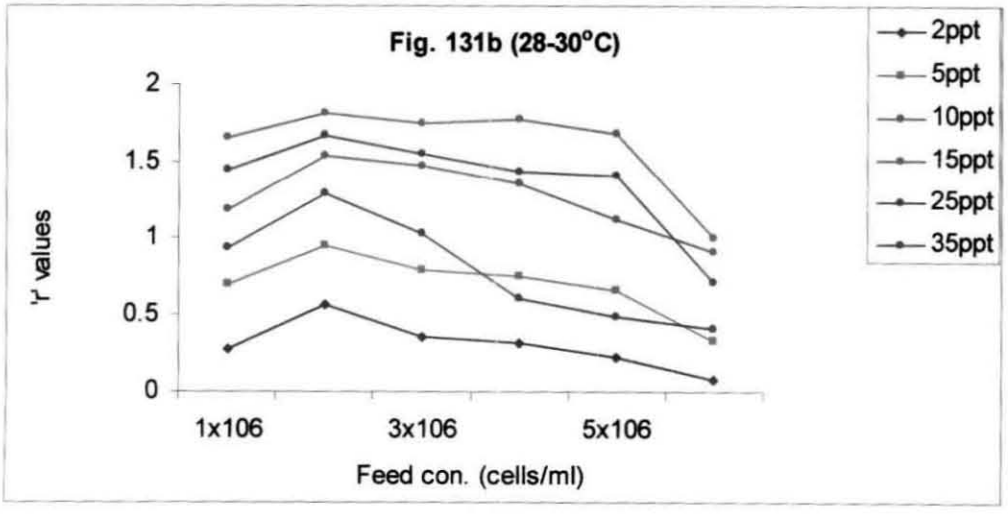
Table 38: Result of three-way ANOVA comparing the reproductive potential of *B. rotundiformis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	23094.65	5	4618.93	97.05	0.00**
Feed concentration	26956.94	5	5391.34	113.28	0.00**
Temperature	13721.28	2	6860.64	144.15	0.00**
Salinity x Feed concentration	5851.34	25	234.05	4.92	0.00**
Feed con. x Temperature	4061.09	10	406.11	8.53	0.00**
Salinity x Temperature	18222.49	10	1822.25	38.29	0.00**
Salinity x Feed con. x Temp	8067.14	50	161.34	3.39	0.00**
Error	10280.00	216	47.59		

(* $p<0.05$; **$p<0.01$)

Fig. 131a-c: Reproductive potential ('r') of *B. rotundiformis* at different salinities and feed concentrations of *Isocrysis galbana* at three temperatures





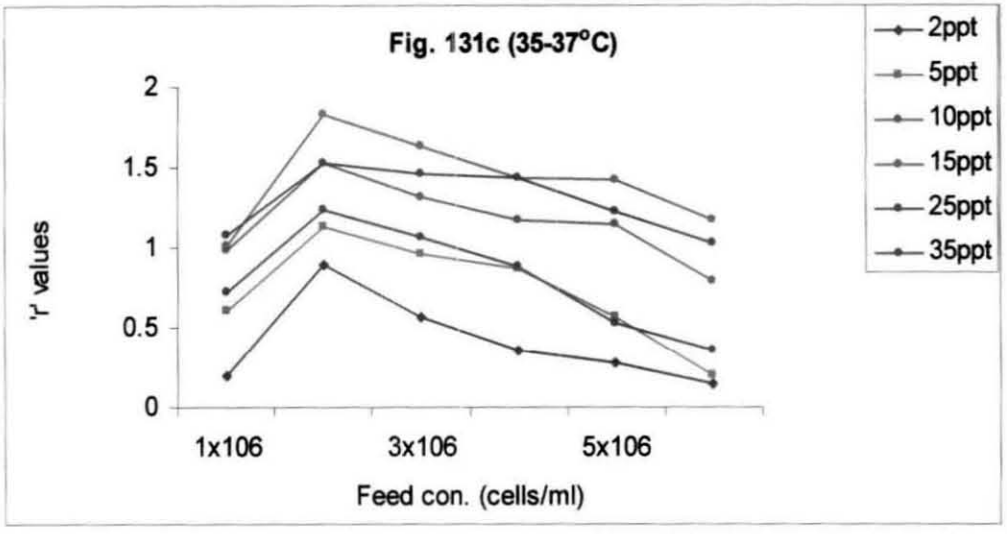
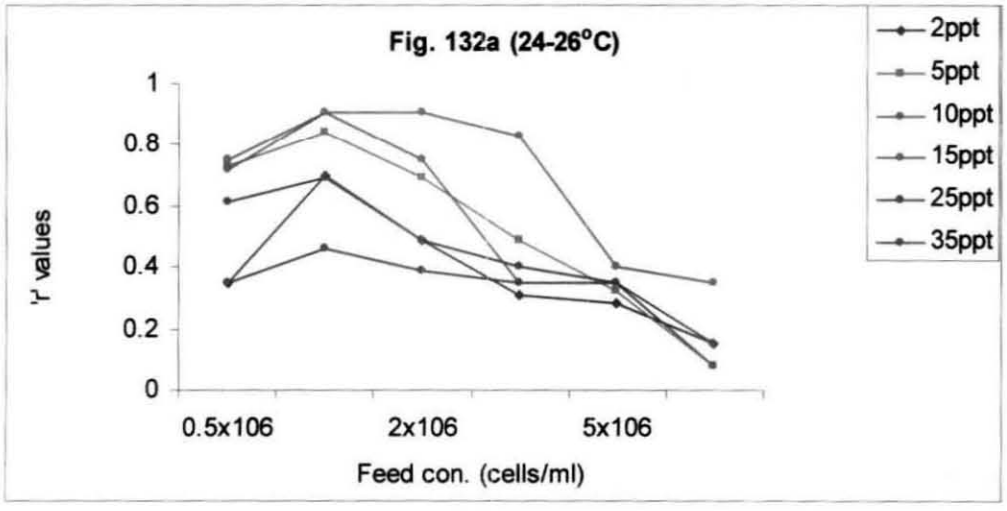


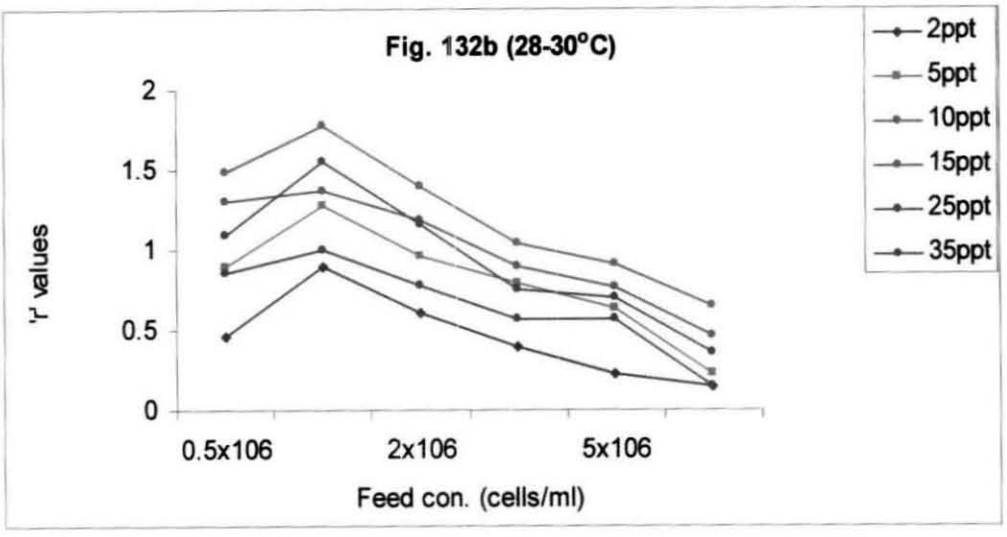
Table 39: Result of three-way ANOVA comparing the reproductive potential of *B. rotundiformis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	293673.79	5	58734.76	214.02	0.00**
Feed concentration	75828.68	5	15165.76	55.26	0.00**
Temperature	133467.23	2	66733.61	243.17	0.00**
Salinity x Feed concentration	77053.04	25	3082.12	11.23	0.00**
Feed con. x Temperature	60438.33	10	6043.83	22.02	0.00**
Salinity x Temperature	151709.11	10	15170.91	55.28	0.00**
Salinity x Feed con. x Temp	74721.12	50	1494.42	5.45	0.00**
Error	59278.00	216	274.44		

(* $p<0.05$; ** $p<0.01$)

Fig. 132a-c: Reproductive potential ('r') of *B. rotundiformis* at different salinities and feed concentrations of *Tetraselmis gracilis* at three temperatures





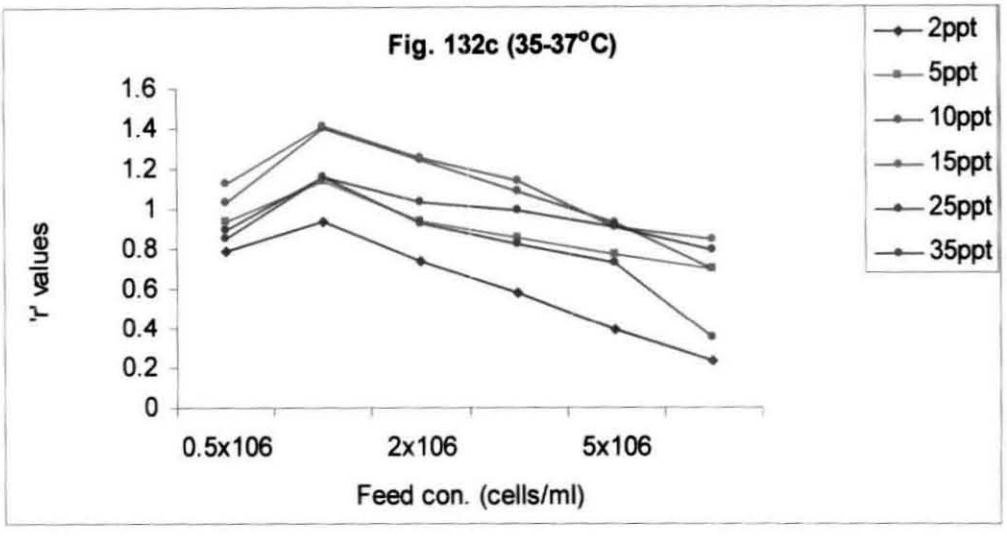
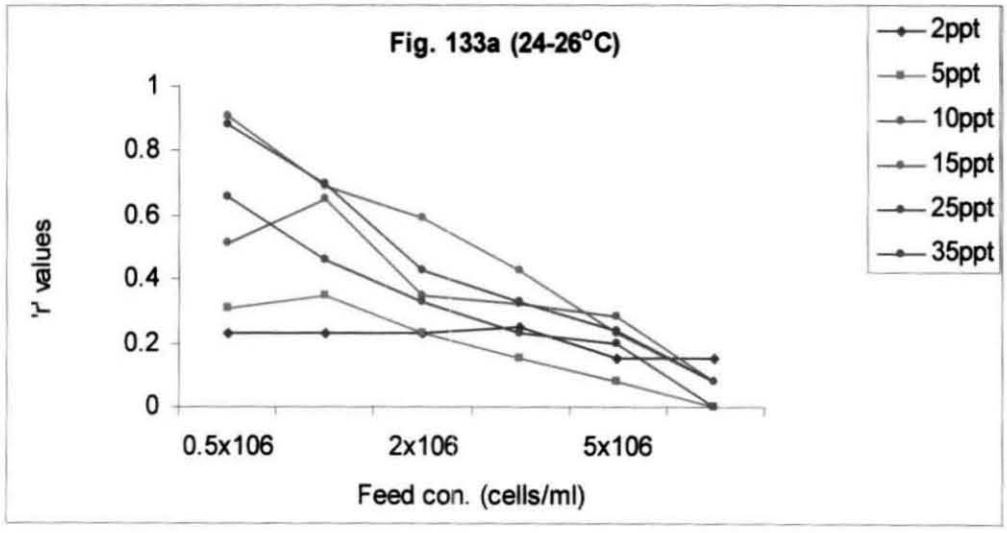


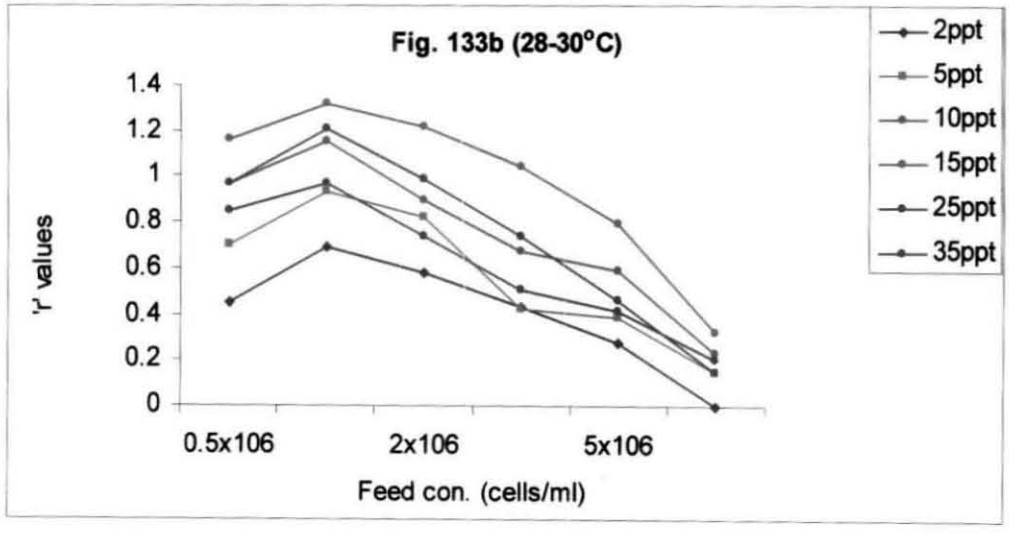
Table 40: Result of three-way ANOVA comparing the reproductive potential of *B. rotundiformis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	36714.10	5	7342.82	127.41	0.00**
Feed concentration	37082.21	5	7416.44	128.69	0.00**
Temperature	24100.64	2	12050.32	209.09	0.00**
Salinity x Feed concentration	29741.12	25	1189.65	20.64	0.00**
Feed con. x Temperature	28360.14	10	2894.28	50.22	0.00**
Salinity x Temperature	29360.14	10	2936.01	50.94	0.00**
Salinity x Feed con. x Temp	39510.64	50	790.21	13.71	0.00**
Error	12448.67	216	57.63		

(* $p<0.05$; **$p<0.01$)

Fig.133a-c: Reproductive potential ('r') of *B. rotundiformis* at different salinities and feed concentrations of *C. calcitrans* at three temperatures





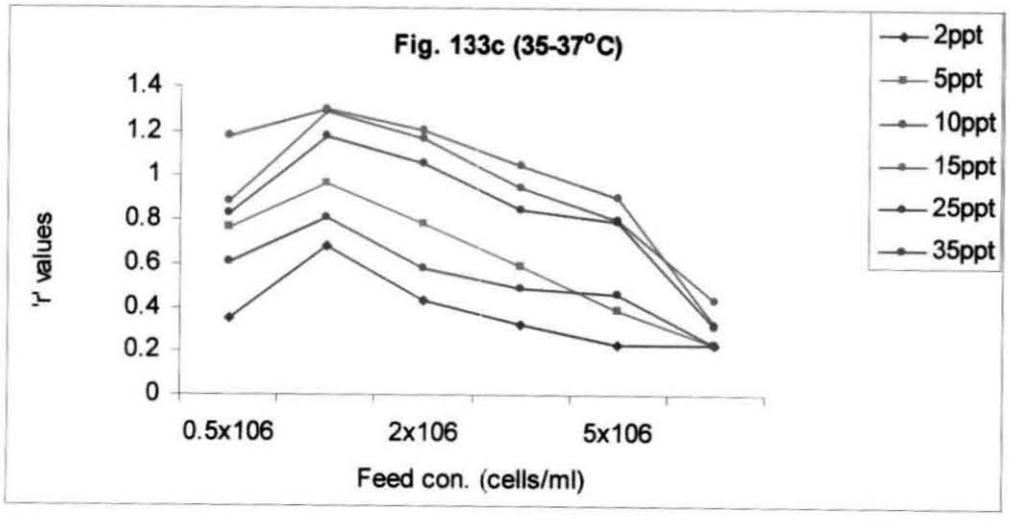
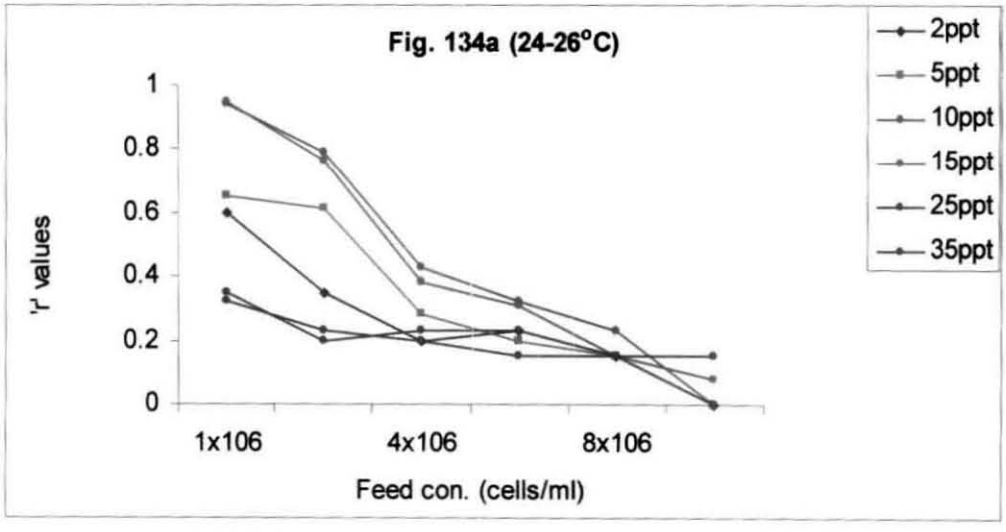


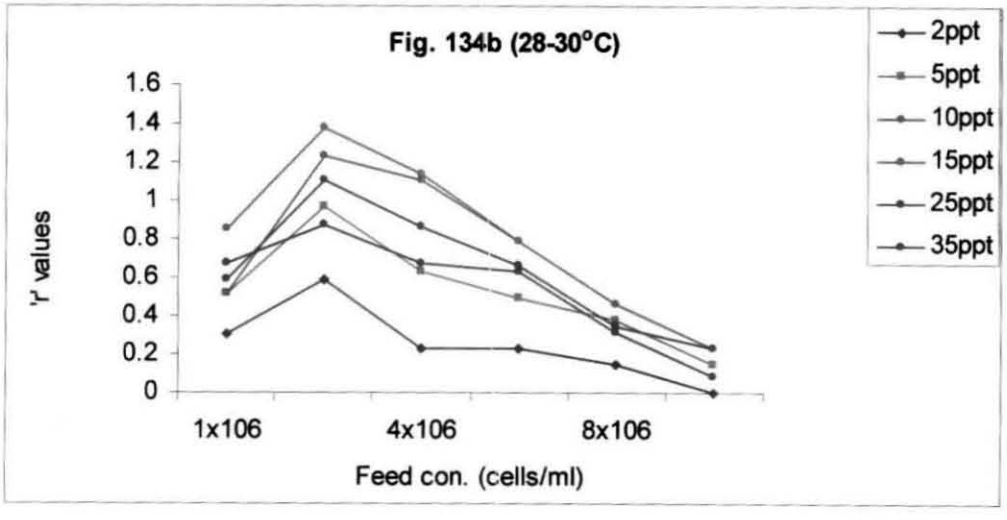
Table 41: Result of three-way ANOVA comparing the reproductive potential of *B. rotundiformis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	10986.59	5	2197.32	193.46	0.00**
Feed concentration	16173.96	5	3234.79	284.80	0.00**
Temperature	7646.06	2	3823.03	336.59	0.00**
Salinity x Feed concentration	7607.67	25	304.31	26.79	0.00**
Feed con. x Temperature	6126.32	10	612.63	53.94	0.00**
Salinity x Temperature	4702.24	10	470.22	41.40	0.00**
Salinity x Feed con. x Temp	465.39	50	93.19	8.21	0.00**
Error	2453.33	216	11.36		

(* $p<0.05$; **$p<0.01$)

Fig. 134a-c: Reproductive potential ('r') of *B. rotundiformis* at different salinities and feed concentrations of *C. infusorium* at three temperatures





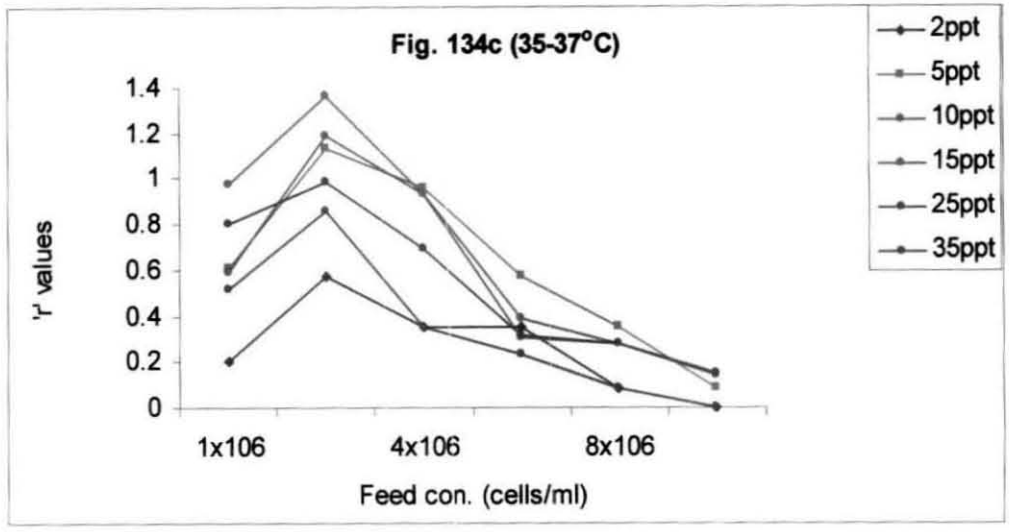


Table 42: Result of three-way ANOVA comparing the reproductive potential of *B. rotundiformis* in relation to salinity, feed concentration and temperature

Source of variation	SS	df	MS	F ratio	P value
Salinity	5879.58	5	1175.92	31.18	0.00**
Feed concentration	13808.18	5	2761.64	73.23	0.00**
Temperature	2730.06	2	1365.03	36.20	0.00**
Salinity x Feed concentration	7345.21	25	293.81	7.79	0.00**
Feed con. x Temperature	4584.13	10	458.41	12.16	0.00**
Salinity x Temperature	2090.39	10	209.04	5.54	0.00**
Salinity x Feed con. x Temp	5843.87	50	116.88	3.10	0.00**
Error	8145.33	216	37.71		

(* $p<0.05$; ** $p<0.01$)

CHAPTER 4

INFLUENCE OF TEMPERATURE AND SALINITY ON THE LIFE HISTORY CHARACTERISTICS OF SELECTED ROTIFERS

INTRODUCTION

Short life cycle, perennial availability and quick parthenogenetic reproduction make rotifers a good material for population dynamic studies. As species population dynamics are the results of the sum of the life histories, exhibited by each individual, it is important to know the parameters of population density. Eventhough, much is known about the biology of many planktonic rotifers, investigations on the life table parameters namely intrinsic rate of increase, reproductive value, predicted age distribution and maximum life duration of the rotifers are scarce.

Several workers had studied the effect of food, temperature and salinity on the life history parameters of various rotifers especially the species belonging to the genus *Brachionus* (King, 1972; Ruttener-Kolisko, 1972; Halbach, 1973; Snell and King, 1977; Vinberg and Galkovskaya, 1979; Galkovskaya, 1987; Walz, 1987, 1997; Korstad *et al.*, 1989; Gopakumar, 1998; Yoshinaga *et al.*, 2003).

The direct positive effect of temperature on physiological rates in individual rotifers and on rotifer populations has been clearly demonstrated. Several of these studies deal with the relationship between temperature and duration of embryonic development. In a wide range of temperature, the duration of embryonic development in rotifer is a curvilinear function of temperature, whereas the same in a limited range of temperature is a linear function of temperature (Edmondson, 1965; Vinberg and Galkovskaya, 1979; Herzig, 1983; Duncan, 1983; Galkovskaya, 1987). The slope of the curve and the absolute rate values are dependent on genotype. The coldwater adapted species have lower slopes and smaller rates than warmwater-adapted species (Galkovskaya, 1987). Therefore, in many cases coldwater-adapted species show faster low temperature development but much slower high temperature development than warm-adapted species and vice-versa. The

effect of temperature is also dependent on its stability. If temperature fluctuates around a mean value, the egg development time deviates from that at the constant mean (Ruttner-Kolisko, 1975, 1978).

It is often assumed that the duration of embryonic development is only dependent upon the temperature (Herzig, 1983). However, relations with other parameters have also been described mainly with egg volume which in turn, is dependent on temperature (Pourriot, 1973) or on the feeding conditions of the mother (Yúfera, 1987). The duration of pre-embryonic and post-embryonic development is also a clear function of temperature and under the same feeding conditions the ratio between the post-embryonic and the embryonic development time remains quite constant (Ruttner-Kolisko, 1975). Thus, the duration of these periods does not deviate significantly from that obtained at the corresponding mean temperature (Ruttener-Kolisko, 1978).

Several workers have estimated the mean lifespan of various rotifer species at different temperatures. King (1967) found that *Euchlanis dialata* live for 3.4 days and 3.76 days at 18°C and 27°C respectively. Hirayama and Kusano (1972), King and Miracle (1980), Nagata (1985) and Snell (1986) have found that *Brachionus plicatilis* lived for 11 days to 16 days, 9 days to 15 days and 6.2 days to 26.5 days at temperatures of 5°C, 14°C and 20°C respectively. Similarly, Walz (1983, 1987) found that *B. angularis* live for about 19.4 days and 2.8 days at 5°C and 25°C respectively. Halbach (1973) and Galkovskaya (1987) have found that *B. calyciflorus* live for about 17.2 days and 1.7 days at 15°C and 37°C respectively. All these studies have clearly illustrated that the lifespan decreases with a rise of temperature, the relationship again being similar to the duration of embryonic and post embryonic development, intervals between egg depositions, etc. Lifespan matches the corresponding acceleration of reproductive efforts with temperature, and an inverse relationship exists between the two responses.

Like temperature, salinity also plays a vital role in the life table parameters of an individual rotifer. Several rotifer genera have halobiont species living in a very wide range of salinities. Salinity is one of the important factors conditioning the rotifer distribution in their natural habitat (Miracle *et al.*, 1987). The influence of salinity is directly related to the osmotic regulation capacity of an individual, which in turn strongly dependent on the genotype and species. Lansing (1942) found that the mean lifespan of *Rotifer vulgaris* decreases with increasing levels of salinity. According to Aranovich and Spektorova (1974), *Brachionus calyciflorus* decreases its survival and fecundity as the salinity rises from 2 ppt to 10 ppt, negative slope being progressively steeped. Miracle *et al.* (1987) found that the lifespan and fecundity of *B. angularis* decreases as salinity rises from 0.5 ppt to 24 ppt. Thus the decrease in growth rate when salinity increases above the optimum, is first due to a decrease in fecundity and second to a decrease in survival.

Parthenogenetically reproducing rotifers have the potential for very high reproductive rates. This is because they have a relatively short pre-reproductive period. The number of oocytes in her germovitellarium limits the total number of offspring that a female can produce. Since rotifers are eutelic and can form no new oocytes after birth, the maximal potential fecundity of a female is fixed. The actual or realized fecundity of a female and this is usually less than the potential fecundity of that female this is to a large extent a function of the environmental conditions in which the female is raised. The more favourable the conditions, the more closely will the realized fecundity approach the potential fecundity. Most experiments have been conducted on amictic monogonont, having examined the influence of temperature, food quantity and food type. The monogonont genus studied by most investigators in this regard is *Brachionus*. Pilarska (1972, 1977) found that the fecundity of both amictic and mictic females of *B. rubens* at 21°C was greater on a diet of the alga *Chlorella vulgaris* than on one of the bacterium *Aerobacter aerogens*, eventhough both food types were present in the same concentration. Halbach (1973) and Hirayama *et al.* (1973) found that both temperature and

phytoplankton density were significantly influenced the egg production (fecundity) in *B. calyciflorus* and *B. plicatilis*.

Pourriot and Rougier (1975) investigated the effects of food type and temperature on the fecundity and reproductive rate of *B. dimidiatus* and found that the population fed on the blue green alga *Synechococcus cedrorum* and a green alga *Dunaliella salina* produced similar numbers of offspring per female at 25°C than at either 20°C or 30°C. Reproduction in *B. patulus* was studied by Rao and Sarma (1988). They found that fecundity increased as the concentration of *Chlorella* sp. increased from 1 – 3 x 10^6 cells/ml. The effect of algal food level, type of food and temperature on the population dynamics of *B. angularis* was analyzed by Walz (1983, 1987) and found that all these factors have a direct effect on the fecundity of this species. Many investigations on the effect of feed quality, feed quantity, and temperature have been conducted on *B. plicatilis*, because this species is widely used as a food for larval fish (Lubzens, 1987). Hirayama and Kusano (1972) and Hirayama *et al.* (1973) studied the effect of feed density and feed type on the life table parameters of *B. plicatilis* at different temperatures and found that the number of offsprings produced per females varied with various temperatures even in the same feed type. Hirayama *et al.* (1979) and Hirayama and Rumengan (1993) compared the fecundity of *B. plicatilis* females cultured different algal species tested at different feed concentrations. This study showed that the fecundity or mechanism triggering fecundity could be greatly affected by feed type. The effect of feed type on fecundity is not known but this must involve a variety of factors such as digestibility, assimilability, nutritional value, toxicity of algae, physiological state of the individuals itself etc. Similarly, several other studies have examined the effect of diet, temperature and salinity on growth, life history parameters of this species and these studies revealed that all these factors significantly influence the life-history characteristics of this taxon (Theilacker and McMaster, 1971; Hirayama *et al.*, 1973; Hirayama, 1985; Korstad *et al.*, 1989; Miracle and Serra, 1989; Gopakumar, 1998 etc,).

From the forgoing, it is clear that the chief environmental factors that affect the life table parameters are temperature, salinity, food quantity, food quality, reproductive type and genotype. Knowledge of the impact of these parameters on life table characteristics of rotifers is a pre-requisite before optimization of the mass production of potential rotifer species. Therefore, this study examines the impact of salinity and temperature on eleven life table parameters of six rotifer species and the results are presented in this chapter.

MATERIAL AND METHODS

A total of six rotifer species namely *Brachionus angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis*, *B. murray* and B. *rotundiformis* maintained in the laboratory were utilized for the experiments. *B. angularis* and *B. caudatus* were maintained in the laboratory by feeding them with *Chlorella ellipsoidea* at a rate of 4 x 10^6 cells/ml and *B. calyciflorus* were maintained by feeding them with the same alga at a rate of 8 x 10^6 cells/ml. The stock culture of *B. plicatilis* was maintained by feeding rotifer with *Chlorococcum infusorium* at a rate of 4 x 10^6 cells/ml and the stock cultures of *B. murray* and B. *rotundiformis* were maintained by feeding each of them with *Chaetoceros calcitrans* and *Isochrysis galbana* at a rate of 2 x 10^6 cells/ml. Six grades of salinities and two temperature ranges were tested for *B. plicatilis*, *B. murray* and *B. rotundiformis*. Similarly, two grades of salinities and two temperature ranges were tested for *B. angularis*, *B. caudatus* and *B. calyciflorus*. For *B. plicatilis*, and *B. murray* the salinity grades were 0.5 ppt, 5 ppt, 10 ppt, 15 ppt, 25 ppt and 35 ppt whereas the same for *B. rotundiformis* were 2 ppt, 5 ppt, 10 ppt, 15 ppt, 25 ppt and 35 ppt. Likewise, for *B. angularis*, *B. caudatus* and *B. calyciflorus* the salinity grades were 0.5 ppt and 5 ppt. The salinity levels were chosen according to the tolerance ranges of the rotifer species studied. Two temperatures such as room temperature (29 ± 1°C) and thermostat temperature (35 ± 1°C) were tested for all the rotifers. The feed type *C. infusorium* at the rate of 4 x 10^6 cells/ml was used for *B. plicatilis* whereas

Chlorella ellipsoidea at a rate of 4 x 10^6 cells/ml was employed for *B. angularis* and *B. caudatus*. Similarly, *Chaetoceros calcitrans* was used for *B. murray* and *Isochrysis galbana* for *B. rotundiformis* at the rate of 2 x 10^6 cells/ml. The feed type *C. ellipsoidea* at a rate of 8 x 10^6 cells/ml was employed for *B. calyciflorus*. The rotifers were acclimatized to the experimental salinity and temperature for one week prior to the experiments. Three ml capacity glass vials were used for the experiments. For reliable statistical interpretation ten replicates of each set of experiments were carried out 0.5 ml of the medium of the appropriate salinity was taken in each of the ten vials for one set of experiments. Six sets of experimental vials at room temperature and a similar six set of experimental vials in a thermostat at 35 $\pm$ 1°C were set up for B. *plicatilis*, *B. murray* and *B. rotundiformis* each. Thus, a total of 180 vials (6 salinities x 2 temperatures x 10 replicates) were set up for each species. Similarly, two sets of experimental vials at room temperature (28 - 30°C) and a similar two sets of experimental vials in the thermostat at 35 - 37°C were set up for *B. angularis*, *B. caudatus* and *B. calyciflorus*. Thus, a total of 40 vials (2 salinities x 2 temperatures x 10 replicates) were set up for each rotifer species.

Egg bearing females (single egg) were randomly selected from the acclimatized stock and individually micropippeted (one in each vial) into the vials containing the medium of the corresponding salinity and temperature to which the animal was acclimatized. The rotifer in each vial was observed every one - two hours under a dissecting microscope by pouring the content of each vial into an embryo cup. As soon as neonate appeared in each vial the mother was removed. Thereafter observations were made every two to eight hrs for the appearance of eggs and neonates, which were counted, measured and removed. The rotifers were transferred to new food daily. Data on 11 life table parameters were recorded namely size at birth, size at first egg production, maximum size, time taken from neonate till first egg production (juvenile period), time taken from neonate till last egg production, egg hatching time, total number of eggs produced (fecundity), maximum

number of eggs carried at one time, reproductive period, post reproductive period and lifespan. The mean values of ten replicates were taken. Difference between means for each life table parameter was analyzed by two - way ANOVA.

RESULTS

Brachionus angularis

The mean and standard deviation of 11 life table parameters of *B. angularis* at room temperature and thermostat temperature are given in Table 43a; the results of two-way ANOVA (F and P values only) of the life table parameters in relation to salinity and temperature are given in Table 43b.

1. Size at birth: Salinity and temperature were not significant in determining the size at birth either independently or combindly. At room temperature the size at birth ranged from 68.4 µm to 99.6 µm at the salinity of 0.5 ppt and from 68.0 µm to 99.6 µm at 5 ppt. At higher temperature it ranged from 85.5 µm to 93.4µm at the salinity of 0.5 ppt and from 68.9 µm to 99.31µm at 5 ppt.

2. Size at first egg production: Size at first egg production did not show any significant relationship with salinity, temperature or salinity x temperature interaction. At room temperature, the size ranged from 94.10 µm to 115.52 µm at the salinity of 0.5 ppt, and from 102.60 µm to 111.05 µm at 5 ppt. Similarly, at higher temperature the mean lorica sizes of 102.91 µm and 102.62 µm were recorded at the salinities of 0.5 ppt and 5 ppt respectively. However, at higher temperature and salinity the mean lorica size at first egg production becomes comparatively smaller than that at room temperature.

3. Maximum size: This variable did not show any significant difference with salinity or temperature or salinity x temperature interaction. At room

temperature, the maximum size range was 111.15 - 128.25 µm at the salinities of 0.5ppt and 5ppt. At higher temperature the size range was from 119.7 µm to 128.27 µm at the salinity of 0.5 ppt and from 111.15 µm to 125.75 µm at the salinity of 5 ppt.

4. Egg hatching time: *B. angularis* showed an expected decrease in embryonic development time with increasing temperature but the values were different for each salinity grade. An analysis of variance showed a highly significant influence of salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$) on embryonic development time. At room temperature, the fastest egg hatching time of 3.01 hrs was noted at salinity of 0.5 ppt. Similarly, at higher temperature ($35 \pm 1^{\circ}C$), the fastest time 0f 2.82 hrs was noted at 0.5ppt.

5. The juvenile period or growth period: The time taken from neonate till first egg production (juvenile period) showed significant relation with salinity ($p<0.01$) alone. At room temperature, the time was shortest (0.36 days) at the salinity of 0.5 ppt and 0.45 days (hours converted into days) at the salinity of 5 ppt. At higher temperature, the time showed a marginal reduction in the different salinities from that at room temperature. The shortest time of 0.49 days (hours converted to days) was noted at the salinity of 0.5 ppt and 0.77 days at the salinity of 5 ppt.

6. Time taken from neonate till last egg production: The duration of egg production showed significance at 1% level with reference to salinity as well as temperature. At room temperature, the longest time of 4.94 days was noted at the salinity of 0.5 ppt. Similarly, at higher temperature, the maximum duration of 4.29 days was recorded at the salinity of 0.5 ppt.

7. Reproductive period: It is the difference between the time taken from neonate till last egg production, and the time taken from neonate till first egg production. Reproductive period also showed significant relation with

salinity ($p<0.01$) and temperature ($p<0.01$). At room temperature, the reproductive period was the maximum (4.57 days) at the salinity of 0.5 ppt and at higher temperature it was also maximum (3.81 days) at the salinity of 0.5 ppt. However, the reproductive span was comparatively short at higher temperature than at room temperature irrespective of salinity differences.

8. Post-reproductive period: It is the difference between the reproductive period and the lifespan. This period was significantly influenced by temperature ($p<0.05$) only. At room temperature it was the shortest (0.14 days) at the salinity of 5 ppt, and 0.33 days at 0.5 ppt. At the higher temperature also the shortest time of 0.15 days was noted at the salinity of 5ppt and 0.25 days at 0.5 ppt.

9. Fecundity: The total number of eggs production (fecundity) showed high significance in relation to salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature, the maximum number of 24 eggs was produced at the salinity of 0.5 ppt. At higher temperature also maximum number of eggs was produced at the same grade of salinity, but the number was reduced at a higher salinity level.

10. Maximum number of eggs carried at one time: It showed significant relation with salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature, the maximum number of five eggs was carried at the salinity of 0.5 ppt, and at higher salinity the number became reduced. A similar trend was also noted at the higher temperature.

11. Lifespan: The lifespan showed significant relation with salinity ($p<0.01$), temperature ($p<0.01$) and the salinity x temperature interaction ($p<0.01$). At room temperature, the longest life span of 5.06 days was noted at the salinity of 0.5 ppt, and at higher temperature it was 4.50 days at the same

grade of salinity. Here also the lifespan became reduced at higher salinity level.

Brachionus caudatus

The mean and standard deviation of the 11 life-table parameters of *B. caudatus* at room temperature and thermostat temperature are given in Table 44a. The results of two-way ANOVA (F and P values only) of the life-table parameters of this species in relation to salinity and temperature are presented in Table 44b.

1. Size at birth: Mean lorica size of the neonate did not show any significant relationship with salinity or temperature or salinity x temperature interaction. The largest and smallest neonates of 133.92 µm and 133.07 µm were recorded at salinities of 0.5 ppt and 5 ppt respectively and the same at higher temperature were 133.73 µm and 132.59 µm.

2. Size at first egg production: Salinity and temperature were not significant in determining the size at first egg production independently or combinedly. The largest size of 165.45 µm and 165.00 µm was noted at 0.5ppt at room temperature and higher temperature respectively.

3. Maximum size: The maximum size attained by the rotifer showed significant variation with temperature ($p<0.05$) only. The average maximum size of 172.12 µm was recorded at the salinity of 0.5 ppt and 171.85 µm at 5 ppt. At room temperature the average maximum sizes of 179.55 µm and 177.7 µm were noted at the same salinity levels.

4. Egg hatching time: This period was found to be significantly affected by temperature ($p<0.01$). At room temperature, the fastest egg hatching time of 6 hrs was noted at the salinity of 0.5 ppt and 9 hrs at 5 ppt. The egg-hatching time was comparatively longer at higher salinity levels. At the higher temperature, the egg hatching time followed the same trend in

relation to salinity, but it was longer than the corresponding time at room temperature. The time taken was only 8 hrs at the salinity of 0.5 ppt followed, and 11 hrs at the salinity of 5 ppt. The hatching time was longer at higher salinity levels.

5. Juvenile period or growth period: This period showed significant relationship with the salinity ($p<0.05$) and temperature ($p<0.01$). At room temperature the time was the shortest, 0.66 days (hours converted into days) at the salinity of 0.5 ppt and 0.79 days at 5 ppt. At higher temperature the time showed a marginal increase in the different salinity levels; the shortest time of 0.74 days was noted at the salinity 0.5 ppt and 0.87 days at 5 ppt.

6. The time taken from neonate till last egg production: This period was significantly affected by salinity ($p<0.01$) alone. At room temperature, the longest time of 3.83 days was recorded at the salinity of 0.5 ppt and 2.75 days at 5 ppt. At the higher temperature, the longest time of 3.37 days was noted at the salinity of 0.5 ppt and1.96 days at 5 ppt.

7. Reproductive period: At both temperatures, the reproductive period showed significant relationship with salinity ($p<0.01$). At room temperature, the reproductive period was a maximum of 3.17 days at salinity 0.5 ppt and 1.95 days at 5 ppt. A similar trend was also observed at higher temperature, but the reproductive period was comparatively shorter at all the salinities. The longest reproductive period of 2.63 days was noted at the salinity of 0.5 ppt, 1.09 days at 5 ppt.

8. Post-reproductive period: This period showed significant relationship with salinity ($p<0.01$) and salinity x temperature interaction ($p<0.01$). The longest post reproductive period of 0.52 days was noted at the salinity of 0.5 ppt at room temperature. At the higher temperature, the longest period of 0.92 days was recorded at the salinity of 5 ppt.

9. Fecundity: The total number of eggs produced by the rotifer showed significant relationship with temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature a maximum number of 13 eggs were produced at the salinity of 0.5 ppt, and seven eggs at 5 ppt. At higher temperature the maximum number of six eggs was produced at the salinity of 0.5 ppt and five eggs at 5 ppt.

10. The maximum number of eggs carried at one time: This variable showed significant relationship with salinity ($p<0.01$) alone. At the salinity of 0.5 ppt the maximum number of three eggs was carried at one time, whereas in other salinity grades the number of eggs carried at one time was reduced to one.

11. Lifespan: It was found to be significantly affected by temperature ($p<0.01$) as well as salinity ($p<0.05$). At room temperature the longest life span of 4.35 days was noted at the salinity of 0.5 ppt and 3.18 days at 5 ppt. At higher temperature it followed the same trend at the different salinity grades, but the life span was reduced at all the salinities when compared to that at room temperature. The longest lifespan of 3.55 days was noted at the salinity of 0.5 ppt and 2.88 days at the 5 ppt.

Brachionus calyciflorus

The mean and standard deviation of 11 life-table parameters of *B. calyciflorus* at room temperature and thermostat temperature are given in Table 45a. The result of two-way ANOVA (F and P values only) of the life-table parameters of *B. calyciflorus* in relation to salinity and temperature are presented in Table 45b.

1. Size at birth: Salinity, temperature or salinity x temperature interaction was not significant in determining the size at birth of *B. calyciflorus*. At room temperature the largest and smallest neonates of 144.21 µm and

142.50 µm were recorded at the salinities of 0.5 ppt and 5 ppt respectively and the same at the higher temperature were 145.20 µm and 144.50 µm at 0.5 ppt and 5 ppt respectively.

2. Size at first egg production: It did not show any significant relationship with salinity, temperature or salinity x temperature interaction. The largest size of 188.93 µm and 188.33 µm was recorded at the salinity of 0.5ppt at both the temperatures.

3. Maximum size: The maximum size attained did not show any significant variation with salinity or temperature either independently or combindly. At the higher temperature the average maximum sizes of 262.03 µm and 250.53 µm were recorded at salinities of 0.5 ppt and 5 ppt respectively. At room temperature the maximum size of 265.05 µm was noted at the salinity of 0.5 ppt.

4. Egg hatching time: This period was found to be significantly affected by salinity ($p<0.01$) only. At room temperature the fastest egg hatching time of 2.66 hrs was noted at the salinity of 0.5 ppt and 3.7 hrs at 5 ppt. The egg hatching time was comparatively longer at higher salinity levels. At the higher temperature it was followed the same trend in relation to salinity, but the hatching time was faster at this temperature than the corresponding time at room temperature. The time taken was only 2.33 hrs at the salinity of 0.5 ppt and 3.0 hrs at 5 ppt.

5. Juvenile period: This period showed significant relationship with the salinity ($p<0.01$). At room temperature the time was the shortest (0.325 days) at the salinity of 0.5 ppt and 0.45 days at 5 ppt. At the higher temperature the time showed a marginal reduction in the different salinities from that at room temperature. The shortest time of 0.38 days was noted at the salinity 0.5 ppt and 0.64 days at 5 ppt.

6. The time taken from neonate till last egg production: This period was significantly affected by salinity ($p<0.01$). At room temperature, the longest time of 5.33 days was recorded at the salinity of 0.5 ppt and 3.83 days at 5 ppt. At the higher temperature, the longest time of 4.93 days was noted at the salinity of 0.5 ppt and 2.83 days at 5 ppt.

7. Reproductive period: This period showed significant relationship with temperature ($p<0.01$) and salinity ($p<0.01$). At room temperature, the longest reproductive period of 5.0 days was noted at the salinity of 0.5 ppt and 3.4 days at 5 ppt. At higher salinity it was comparatively shorter. A similar trend was also observed at higher temperature, but the period was comparatively short at all the salinity levels. The longest reproductive period of 4.55 days was recorded at the salinity of 0.5 ppt and 2.19 days at 5 ppt.

8. Post-reproductive period: This period was significantly influenced by salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). The longest post-reproductive period of 0.4 days was noted at the salinity of 0.5 ppt at room temperature. At the higher temperature, the period was shorter than at the room temperature.

9. Fecundity: The total number of eggs produced showed high significance with salinity ($p<0.01$) and temperature ($p<0.01$). At room temperature, maximum number of 34 eggs was recorded at the salinity of 0.5 ppt and 19 eggs at 5ppt. At higher temperature maximum number of 25 eggs was produced at the salinity of 0.5 ppt and 8 eggs at 5 ppt.

10. Maximum number of eggs carried at one time: It showed significant relationship with salinity ($p<0.01$) and temperature ($p<0.01$). At the salinity of 0.5 ppt the maximum number of four eggs was carried at one time whereas in other salinity grade the maximum number of eggs carried at one time was reduced to two.

11. Lifespan: This life table parameter was found to be significantly affected by ($p<0.05$) temperature as well as salinity ($p<0.01$). At room temperature the longest life span of 5.68 days was noted at the salinity of 0.5 ppt and 4.35 days at 5ppt. The higher temperature followed the same trend in the different salinity grades, but the time was decreased in all the salinities when compared to that at room temperature. The longest lifespan of 5.30 days was recorded at the salinity of 0.5 ppt followed by 3.58 days at 5ppt.

Brachionus plicatilis

The mean and standard deviation of 11 life-table parameters of *B. plicatilis* at room temperature and thermostat temperature are given in table 46a and b respectively. The result of two-way ANOVA (F and P values only) of the life-table parameters of this rotifer in relation to salinity and temperature are presented in Table 46c.

1. Size at birth: The average lorica size of neonates was significantly influenced by salinity ($p<0.01$) and temperature ($p<0.05$). At room temperature, the largest neonate of 148.92 µm was noted at the salinity of 5ppt, whereas the smallest of 145.64 µm was recorded at 35ppt. At higher temperature the average largest (144.82µm) and smallest (142.56µm) neonates were noted at the salinities of 5 ppt and 35 ppt respectively.

2. Size at first egg production: This variable showed significant relationship with salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature largest mean lorica size of 189.92 µm was recorded at the salinity of 5 ppt and 188.67 µm at 0.5 ppt. At the higher temperature, the size at first egg production was the largest (186.44 µm) at the salinity of 0.5 ppt and185.79 µm at 5 ppt.

3. Maximum size: The maximum size attained by the rotifer showed significant relationship with salinity ($P<0.01$) and temperature ($p<0.01$). At

room temperature, the average maximum size attained was 262.74 µm at the salinity of 5 ppt and 261.94 µm at 0.5 ppt. The lowest size of 257.10 µm was recorded at the salinity of 35 ppt. At higher temperature, a general decrease in size at all the salinity grades was noted. The average maximum size of 256.93 µm was observed at the salinities of 0.5 ppt and 5 ppt while the lowest size of 239.99 µm was noted at 5 ppt.

4. Egg hatching time: Temperature ($p<0.01$) and salinity ($p<0.01$) exhibited significant relationship with the egg hatching time. At room temperature, the egg hatching time was short (3.13 hrs) at the salinity of 5 ppt and 3.26 hrs at 0.5 ppt. The time increased with the increase in salinity. The same trend with regard to salinity was noted at the higher temperature. But the egg hatching time was shorter than the same at the corresponding salinity grades at room temperature. At thermostat temperature, the shortest egg hatching time of 2.77 hrs was recorded at the salinity of 5 ppt and 2.93 hrs at 0.5 ppt. At the higher salinities also the time taken was comparatively shorter than their corresponding time at room temperature.

5. Juvenile period: Temperature and salinity exhibited significant $p<0.01$) relationship in the time taken from neonate till first egg production. At room temperature, the least time of 0.54 days was noted at the salinity of 5 ppt and 0.58 days at 0.5 ppt. The higher salinities tested showed proportionately longer periods for the first egg production. The higher temperature also exhibited the same trend with regard to salinity as was seen at room temperature. But the time taken was less when compared to the same at room temperature. The least time of 0.47 days was noted at 5 ppt and 0.51 days at 0.5 ppt.

6. The time taken from neonate till last egg production: This period was found to be significantly affected by salinity ($p<0.01$) as well as temperature ($p<0.01$). However, the time taken from neonate till last egg production showed a marginal decrease from lower salinity levels to higher

salinity levels at both temperature grades. At room temperature the time taken from neonate till last egg production was 4.84 days at the salinity of 5 ppt and 4.73 days at 0.5 ppt. Similarly, at the higher temperature the longest period of 4.67 days was recorded at the salinity of 5 ppt and 4.12 days at 0.5 ppt.

7. Reproductive period: This period was significantly affected by salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.05$). At room temperature, the longest reproductive period of 4.29 days was recorded at the salinity of 5 ppt and 4.16 days at 0.5 ppt. At the higher salinities the reproductive periods were comparatively shorter. The same trend was noted at the higher temperature with regard to the salinity grades. At higher temperature, the longest reproductive period of 4.20 days was noted at the salinity of 5 ppt and 3.46 days at the salinity of 0.5 ppt.

8. Post-reproductive period: This period was significantly influenced by salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature the longest post reproductive period of 1.44 days was noted at the salinity of 15 ppt whereas the same at higher temperature was 1.95 days at 10 ppt.

9. Fecundity: The total number of eggs produced was significantly more influenced by salinity x temperature interaction ($p<0.01$) than the individual variables. At room temperature, the maximum number of 18 eggs was produced at the salinities of 0.5 ppt and 5 ppt. The least number of five eggs was produced at the salinity of 35 ppt. At higher temperature, the total number of 16 eggs was produced at the salinity of 0.5 ppt and 14 eggs 5 ppt.

10. Maximum number of eggs carried at one time: It was significantly influenced by temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). A maximum of three eggs was carried at one time at the salinity of 5 ppt and only upto two eggs were carried at one time at the higher salinities at both temperatures.

11. Lifespan: The salinity, temperature and salinity x temperature were significant with regard to the lifespan. But at the higher salinities the lifespan was comparatively reduced at both temperature levels. At room temperature, the longest lifespan of 5.77 days was recorded at the salinity of 5 ppt and 5.72 days at 0.5 ppt. Similarly, at higher temperature, the longest lifespan of 5.58 days and 5.03 days was noted at the salinities of 5 ppt and 0.5 ppt respectively.

Brachionus murray

The mean and standard deviation of 11 life-table parameters of *B. murray* at room temperature and thermostat temperature are given in Table 47a and 47b respectively. The result of two-way ANOVA of the life-table parameters of this taxon in relation to salinity and temperature are presented in Table 47c.

1. Size at birth: The size of neonates did not show any significant variation with any of the tested variables. At room temperature, largest and smallest neonates of 137.40 µm and 136.11 µm were recorded at the salinities of 10 ppt and 35 ppt respectively and the same at thermostat temperature were 137.42 µm and 132.90 µm at 0.5 ppt and 35 ppt respectively.

2. Size at first egg production: It did not show any significant variation with salinity or temperature. However, at higher salinities of 25 ppt and 35 ppt, the size at first egg production became smaller at both temperatures.

3. Maximum size: This variable showed significant variation with temperature ($p<0.05$). At the higher temperature the average maximum size of 222.98 µm was recorded at the salinity of 10 ppt and 221.02 µm at 5 ppt. At room temperature the average largest size of 223.50 µm was noted at the salinity of 10 ppt and 221.70 µm at 15ppt.

4. Egg hatching time: The egg hatching time was found to be significantly affected by salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature, the fastest egg hatching time of 2.72 hours was noted at the salinity of 10 ppt and 2.87 hours at 15 ppt. The egg hatching time was comparatively longer at higher salinity levels. At the higher temperature, the egg hatching time followed the same trend as that recorded for salinity, but the hatching time was shorter than the corresponding time at room temperature. The time taken was 2.50 hours at the salinity of 10 ppt and 2.70 hrs at 15 ppt. The hatching time was longer at higher salinity levels.

5. Juvenile period: The time taken from neonate till first egg production showed significant relationship with the salinity ($p<0.05$) and temperature ($p<0.01$). At room temperature, the shortest time of 0.57 days was noted at the salinity of 10 ppt and 0.68 days at 0.5ppt. At higher salinities it was comparatively higher. At the higher temperature, the shortest time of 0.53 days was recorded at the salinity 10 ppt and 0.61 days at 5 ppt.

6. The time taken from neonate till last egg production: This period was significantly affected by salinity $p<0.01$) and temperature ($p<0.01$). At room temperature, the longest time of 4.89 days was recorded at the salinity of 10 ppt and 4.04 days at 15 ppt. A more or less similar period was noted at the salinity of 5 ppt (3.87days) and at salinities above or below this range the time became shorter. At the higher temperature, the longest time of 4.59 days was noted at the salinity of 10 ppt and 3.66 days at 15 ppt. Here also, the time became shorter at salinities above or below this range.

7. Reproductive period: This period showed significant relationship with salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature the maximum reproductive period of 4.22 days was recorded at the salinity of 10 ppt and 3.4 days at 15 ppt. The reproductive period was comparatively shorter at higher salinities at both

temperatures. At thermostat temperature the longest reproductive period of 3.87 days was noted at the salinity of 10 ppt and 3.05 days at 15 ppt.

8. Post-reproductive period: This period was significantly influenced by salinity ($p<0.01$) alone. The longest post reproductive period of 0.91days was noted at the salinity of 25 ppt at room temperature. A similar trend was noted in all the salinities at the higher temperature, but the period were comparatively shorter than that recorded at room temperature.

9. Fecundity: The total number of eggs produced showed high significance ($p<0.01$) with the salinity x temperature interaction. At room temperature, maximum number of 24 eggs was produced at the salinity of 10 ppt and 22 eggs at 5 ppt. At higher temperature more or less same number of eggs was produced at the salinity of 10 ppt and at 5 ppt (24 and 20 eggs respectively).

10. Maximum number of eggs carried at one time: It showed significant relationship with salinity ($p<0.05$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.05$). At the salinities of 0.5 ppt, 5 ppt and 10 ppt the maximum number of three eggs was carried at one time whereas in other salinities the maximum number of eggs carried at one time was reduced. The pattern was same at the higher temperature also.

11. Lifespan: This period was significantly affected by temperature ($p<0.01$) as well as salinity ($p<0.01$). At room temperature, the average longest lifespan of 5.65 days was noted at the salinity of 10 ppt and 4.47 days at 15 ppt and either above or below this salinity range the lifespan was shorter. At higher temperature it followed the same trend at different salinity grades, but the time was decreased at all the salinities when compared to that at room temperature. The longest lifespan of 5.50 days was recorded at the salinity of 10 ppt and 4.21 days at 15 ppt.

Brachionus rotundiformis

The mean and standard deviation of 11 life-table parameters of *B. rotundiformis* at room temperature and thermostat temperature are given are Tables 48a and 48b respectively. The result of two-way ANOVA (F and P values only) of the life-table parameters in relation to salinity and temperature are presented in Table 48c.

1. Size at birth: Size at first egg production was significant with salinity ($p<0.01$) and temperature ($p<0.01$). At room temperature, the largest and smallest neonates of 98.83 µm and 94.50 µm were recorded at the salinities of 5 ppt and 35 ppt respectively and the same at higher temperature were - 96. 68 µm at 2 ppt and 91.80 µm at 35 ppt respectively.

2. Size at first egg production: This variable did not show any significant variation with salinity and temperature either individually or combindly. At higher salinities of 25 ppt and 35 ppt, the mean size became smaller at both temperatures. The largest and smallest values of 118.32 µm and 109.40 µm were recorded at the salinities of 2 ppt and 35 ppt respectively and the same at thermostat temperature were 118.59 µm and 115.30 µm at 10 ppt and 35 ppt respectively.

3. Maximum size: The maximum size attained by the rotifer showed significant variation with temperature ($p<0.05$) alone. At room temperature the maximum size of 173.83 µm was noted at the salinity of 15 ppt and the lowest size of 170.06 µm was noted at 2 ppt. At higher temperature, the maximum and minimum values of 176.06 and 171.13 were recorded at the salinities of 15ppt and 35ppt.

4. Egg hatching time: The egg hatching time was significantly influenced by temperature ($p<0.01$) as well as salinity ($p<0.01$). At room temperature the fastest egg hatching time of 2.84 hrs was noted at the salinity

of 15 ppt and 3.08 hrs at 25 ppt. The time taken above or below this salinity range was higher. At higher temperature, the fastest egg hatching time of 2.76 and 2.99 was noted at 25 ppt and 10 ppt respectively.

5. Juvenile period: The time taken from neonate till first egg production (juvenile period) showed high significance with salinity ($p<0.01$) as well as temperature ($p<0.01$). At room temperature, the longest and shortest juvenile period of 0.98 days and 0.61 days was recorded at the salinities of 35 ppt and 15 ppt respectively. At the higher temperature, the shortest and longest time of 0.45 days and 0.88 days was recorded at the salinities of 15 ppt and 35 ppt respectively.

6. The time taken from neonate till last egg production: This period was significantly affected by salinity ($p<0.01$), temperature ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature the time was longest, 5.13 days at the salinity of 15 ppt and 3.14 days at 10 ppt. At the higher temperature, the time was longest, 4.37 days at the salinity of 25 ppt. The time became shorter at salinities above or below this range.

7. Reproductive period: This period was significantly influenced by salinity ($p<0.01$) alone. At room temperature, the reproductive period was longest, 4.12 days at the salinity of 15 ppt and 3.34 days at 10 ppt. At higher salinities the reproductive period was comparatively less. At higher temperature, it followed the same trend at different salinities, but the reproductive period was slightly longer for all salinities. The longest reproductive period of 4.68 days was noted at the salinity of 15 ppt and 2.44 days at 10 ppt.

8. Post-reproductive period: It showed significant relationship with salinity ($p<0.01$) and salinity x temperature interaction ($p<0.01$). At room temperature the longest post reproductive period of 1.35 days was noted at

the salinity of 15 ppt and the same noted at higher temperature was 1.15 days at the same salinity level.

9. Fecundity: The total number of eggs produced showed high significance with salinity ($p<0.01$) and temperature ($p<0.01$). At room temperature, maximum number of 22 eggs was produced at the salinity of 15 ppt and 18 eggs at 10 ppt. At the higher temperature, the maximum number of 15 eggs was produced at the salinity of 15 ppt and nine eggs at 10 ppt. At lower salinities the egg production becomes decreased.

10. The maximum number of eggs carried at one time: This variable showed significant relationship with salinity ($p<0.01$). The maximum number of four eggs at one time was noted at the salinity of 15 ppt and at higher salinities the number of eggs carried at one time became reduced at both temperatures.

11. Lifespan: The influence of temperature ($p<0.01$) as well as salinity ($p<0.01$) on lifespan is significant. At room temperature the longest lifespan of 5.86 days was noted at the salinity of 15 ppt and 3.99 days at 25 ppt. At the higher temperature, it followed the same trend at the different salinity grades and it did not show much variation between the temperatures tested.

DISCUSSION

The result of the study indicate that the life-table parameters are vitally affected by salinity as well as temperature and this in turn influences the reproductive rate and other population characteristics of the respective rotifer species. At the salinity of 0.5 ppt *B. angularis*, *B. caudatus* and *B. calyciflorus* attained their maximum size, shortest juvenile period, maximum reproductive period, least egg hatching time, maximum fecundity, maximum number of eggs carried at one time and maximum lifespan and above this salinity level

the life table parameters deviated from the above which resulted in a decrease in the fecundity, reproductive period and lifespan. Similarly, *B. plicatilis*, *B. murray* and *B. rotundiformis* attained their maximum size, shortest juvenile period, longest reproductive period, least egg hatching time, maximum fecundity, maximum number of eggs carried at one time and maximum lifespan were recorded at the salinities of 5 ppt, 10 ppt and 15 ppt respectively. Above or below this salinity almost all the life table parameters were declined. The present findings corroborate with the results given in the chapter 3. According to the reproductive potential study the best salinity for the highest 'r' value for each taxon was recorded at the salinities of 5 ppt, 10 ppt and 15 ppt respectively. Thus, the results of the present study clearly illustrated that salinity plays a crucial role in the life-table parameters of these rotifers and they showed their preference to different salinity levels. The direct influence of salinity on the life table parameters of various rotifers both freshwater and halobiont rotifers were observed by a number of workers. Miracle and Serra (1989) found that the direct effects of salinity on life table parameters of a rotifer species are strongly dependent on its osmotic regulatory capacity, which in turn directly dependent on the species and their genotype. Aranovich and Spektorova (1974) noted a decrease in the growth rate survival and fecundity of *B. calyciflorus* when the salinity increases from 2 ppt to 10 ppt, due to a decrease in fecundity and survival. Miracle *et al.* (1987) found that the reproductive rate, survival and fecundity of *B. angularis* decreased when salinity increases from 0.5 ppt to 24 ppt. Similarly, Pourriot and Rougier (1975) noted a decrease in reproductive rate, fecundity and survival rate of *B. dimidiatus* when salinity increased from zero ppt to 25 ppt. Lubzens (1987) also found that reproductive rate, survival and other related life-table parameters changed with salinity. The halobiont rotifers especially *B. plicatilis* and its allied species grew well in a very broad range of salinities, but the optimum values were located at moderate salinities between 10 ppt 20 ppt. Gopakumar (1998) studied the different strains of *B. plicatilis* (both 'L' type and 'S' type) at different temperature and salinity. According to him the best salinities for the reproduction, growth and life-table parameters of *B.*

plicatilis 'L' type and 'S' type was at 2.5 ppt and 10 ppt respectively. However, in the present study the rotifers namely *B. plicatilis*, *B. murray* and *B. rotundiformis* showed more tolerance capacity towards lower salinity levels than the salinity range reported by Lubzens (1980, 1985, 1987) and Gopakumar (1998). *B. plicatilis* recorded its best performance on the various life-table parameters at the salinity of 5 ppt while *B. murray* showed its best performance at the salinity of 10 ppt. Likewise, *B. rotundiformis* recorded its optimum values for different life-table parameters at the salinity of 15 ppt. The difference between the salinity ranges reported by Lubzens (1985, 1987) and the present study may be due to the geographical strain variation of these species. Similarly, the present study also showed marginal variation with the findings of Gopakumar (1998) and this variation may be due to the application of more suitable feed types (*I. galbana*, *C. calcitrans* and *C. infusorium* used in the present study instead of *C. marina*, *T. gracilis* and yeast by Gopakumar, 1998) for rearing rotifers since salinity, temperature and potential food resources are the important external factors in determining the reproductive output, fecundity, growth, survival and other life table parameters of rotifers.

Temperature also plays a vital role in the determining the life table characteristics of rotifers. Temperature and salinity interaction was significant in the determination of certain life-table parameters such as fecundity, post-reproductive period, egg hatching time and lifespan. Temperature gave a rather different performance for different rotifers. At the different grade of salinities, the room temperature gave better performance than their corresponding salinity grades at higher temperature. However, *B. rotundiformis* gave a more or less the same performance at both the temperatures at different salinity levels. The shortest egg hatching time was noted at higher temperature for all the studied rotifer species. Vinberg and Galkovskaya (1979), Herzig (1983), Duncan (1983) and Galkovskaya (1987) have demonstrated that a clear relationship between embryonic development and increase in temperature. The duration of the embryonic development is decreased with increasing temperature within their optimum range (Herzig,

1983). In the present study also the duration of the embryonic development decreased at the higher temperature and this is in agreement with the findings of authors cited above. Similarly, lifespan also showed a significant relationship with temperature. Lifespan decreased with a rise of temperature and the relationship again being similar to the duration of embryonic development and post-embryonic development. At higher temperature, the lifespan of *B. angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis* and *B. murray* was marginally reduced at all the salinity grades whereas *B. rotundiformis* did not show much variations between the tested range of temperature. A similar relationship between temperature and lifespan had been reported by Herzig (1983) in *B. angularis*, Galkovskaya (1987), in *B. calyciflorus*, Walz (1987, 1997) in *B. angularis* and *Keratella cochlearis* and Ito *et al.* (1981) and Yúfera (1987) in *B. plicatilis* and *B. rotundiformis*. Thus, the present study had revealed that the ideal temperature for the better performance of the various life-table parameters of *B. angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis* and *B. murray* is at 28 - 30°C whereas the ideal temperature range for the optimum performance of *B. rotundiformis* is at 28 - 37°C.

Table 43a: Mean and SD of 11 life table parameters of *Brachionus angularis* at different salinities and two temperatures

S.N	Parameters/ salinity	28-30°C 0.5 ppt Mean ± SD	28-30°C 5 ppt Mean ± SD	35-37°C 0.5 ppt Mean ± SD	35-37°C 5 ppt Mean ± SD
1.	Size at birth (µm)	87.55 ± 2.1	87.00 ± 4.4	87.10 ± 3.4	86.30 ± 4.3
2.	Size at first egg production (µm)	102.6±10.6	103.3±8.84	102.9±7.93	102.6± 6.78
3.	Maximum size (µm)	124.68 ± 5.9	122.30±3.9	121.41±7.8	118.35± 4.4
4.	Egg hatching time (hrs)	3.01 ± 0.03	4.31 ± 0.04	2.82 ± 0.32	7.07 ± 0.93
5.	Juvenile period (days)	0.36 ± 0.14	0.45 ± 0.93	0.49 ± 0.02	0.77 ± 0.13
6.	Time taken from neonate till last egg production (days)	4.94 ± 0.61	2.93 ± 0.55	4.29 ± 1.32	2.84 ± 0.98
7.	Reproductive period (days)	4.57 ± 1.10	2.44 ± 1.10	3.81 ± 0.37	2.07 ± 0.43
8.	Post reproductive period (days)	0.33 ± 0.25	0.14 ± 0.07	0.25 ± 0.07	0.15 ± 0.03
9.	Total number of eggs produced	24 ± 3	13 ± 2	10 ± 2	5 ± 3
10.	Maximum number of eggs carried at one time	5± 1	3 ± 1	2 ± 1	1 ± 1
11.	Lifespan (days)	5.06 ± 1.23	3.06 ± 0.97	4.50 ± 2.12	2.96 ± 1.37

Table 43b: Result of two-way ANOVA (F and P values only) of life table parameters of *Brachionus angularis* in relation to salinity and temperature

S l. No	Parameters /Source of variation	Temperature F value	P value	Salinity F value	P value	Temp x Salinity F value	P value
1.	Size at Birth (µm)	0.00	1.00	0.002	0.97	0.030	0.86
2.	Size at First egg production (µm)	102.1	0.00**	146.7	0.00**	23.85	0.00**
3.	Maximum size(µm)	0.856	0.36	3.416	0.07	4.358	0.01**
4.	Juvenile period (days)	102.2	0.00**	146.7	0.00**	21.19	0.00**
5.	Time taken from neonate till last egg production (days)	217.1	0.00**	21.57	0.00**	2.695	0.02
6.	Egg hatching time (hrs)	214.3	0.00**	47.44	0.00**	62.16	0.00**
7.	Total number of eggs produced	254.00	0.00**	417.69	0.00**	33.79	0.00**
8.	Maximum number of eggs carried at one time	56.89	0.00**	98.00	0.00**	5.556	0.00**
9.	Reproductive period (Days)	249.94	0.00**	21.57	0.00**	2.70	0.03
10.	Post reproductive period (days)	4.564	0.04	0.263	0.61	0.412	0.53
11.	Lifespan (days)	252.2	0.00**	13.29	0.00**	23.86	0.00**

* $p<0.05$; ** $p<0.01$

Table 44a: Mean and SD of 11 life table parameters of *Brachionus caudatus* at different salinities and two temperatures

S.N	Parameters/ salinity	28-30°C 0.5 ppt Mean ± SD	28-30°C 5 ppt Mean ± SD	35-37°C 0.5 ppt Mean ± SD	35-37°C 5 ppt Mean ± SD
1.	Size at birth (µm)	133.92 ± 2.9	133.07±3.6	133.73±2.9	132.59± 3.5
2.	Size at first egg production (µm)	165.45±2.4	163.13±0.6	165.00±2.3	159.13±1.0
3.	Maximum size (µm)	179.50 ± 5.9	177.70±3.9	172.12±7.8	171.85± 4.4
4.	Egg hatching time (hrs)	6.00 ± 1.0	9.00 ± 1.0	8.00 ± 1.0	11.00 ± 1.2
5.	Juvenile period (days)	0.66 ± 0.05	0.79 ± 0.01	0.74 ± 0.03	0.87 ± 0.04
6.	Time taken from neonate till last egg production (days)	3.83± 0.15	2.75 ± 0.03	3.37 ± 0.36	1.96 ± 0.02
7.	Reproductive period (days)	3.17 ± 0.41	1.95 ± 0.04	2.63 ± 0.35	1.09 ± 0.20
8.	Post reproductive period (days)	0.52 ± 0.44	0.44 ± 0.12	0.18 ± 0.03	0.92 ± 0.30
9.	Total number of eggs produced	13 ± 2	7 ± 2	6 ± 3	5 ± 1
10.	Maximum number of eggs carried at one time	3 ± 1	1 ± 1	2 ± 1	1 ± 0
11.	Life span (days)	4.35 ± 0.09	3.18 ± 0.36	3.55 ± 0.30	2.88 ± 0.10

Table 44b: Result of two-way ANOVA (F and P values only) of life table parameters of *Brachionus caudatus in* relation to salinity and temperature

S l. No	Parameters /Source of variation	Temperature F value	Temperature P value	Salinity F value	Salinity P value	Temp x Salinity F value	Temp x Salinity P value
1.	Size at Birth (µm)	0.038	0.85	0.334	0.58	0.009	0.94
2.	Size at first egg production (µm)	2.638	0.14	9.338	0.02	1.875	0.21
3.	Maximum size(µm)	4.529	0.05	0.116	0.74	0.064	0.81
4.	Juvenile period (days)	15.293	0.00**	44.80	0.00**	0.042	0.84
5.	Time taken from neonate till last egg production (days)	8.234	0.02	33.29	0.00**	0.595	0.46
6.	Egg hatching time (hrs)	12.00	0.01**	41.54	0.00**	0.566	0.47
7.	Total number of eggs produced	16.06	0.00**	3.586	0.09	5.625	0.00**
8.	Maximum number of eggs carried at one time	4.50	0.01**	27.06	0.00**	0.00	1.00
9.	Reproductive period (days)	10.57	0.00**	60.53	0.00**	2.72	0.14
10.	Post reproductive period (days)	0.161	0.69	24.50	0.00**	4.50	0.00**
11.	Lifespan (days)	12.96	0.00**	36.00	0.00**	2.61	0.15

* $p<0.05$; ** $p<0.01$

Table 45a : Mean and SD of 11 life table parameters of *Brachionus calyciflorus* at different salinities and two temperatures

S.N	Parameters/ salinity	28-30°C 0.5 ppt Mean ± SD	28-30°C 5 ppt Mean ± SD	35-37°C 0.5 ppt Mean ± SD	35-37°C 5 ppt Mean ± SD
1.	Size at birth (µm)	144.21 ± 9.7	142.5 ± 7.9	145.2 ± 6.5	144.5 ± 9.4
2.	Size at first egg production (µm)	188.93±5.4	187.84±8.8	188.33±7.9	185.38± 6.7
3.	Maximum size (µm)	265.05 ± 5.9	262.31±3.9	262.03±7.8	250.53± 4.4
4.	Egg hatching time (hrs)	2.66 ± 0.03	3.71 ± 0.04	2.33 ± 0.32	3.0 ± 0.93
5.	Juvenile period (days)	0.33 ± 0.14	0.45 ± 0.43	0.38 ± 0.02	0.64 ± 0.23
6.	Time taken from neonate till last egg production (days)	5.33 ± 0.61	3.83 ± 0.51	4.93 ± 0.32	2.83 ± 0.78
7.	Reproductive period (days)	5.00± 0.40	3.39 ± 0.10	4.55 ± 0.37	2.19 ± 0.33
8.	Post reproductive period (days)	0.68 ± 0.25	0.96 ± 0.07	0.37 ± 0.02	1.39 ± 0.03
9.	Total number of eggs produced	34 ± 2	19 ± 1	25 ± 2	8 ± 2
10.	Maximum number of eggs carried at one time	4 ± 1	2 ± 1	3 ± 1	1 ± 1
11.	Life span (days)	5.68 ± 1.4	4.35 ± 0.95	5.30 ± 1.12	3.58 ± 1.2

Table 45b: Result of two-way ANOVA (F and P values only) of life table parameters of *Brachionus calyciflorus* in relation to salinity and temperature

S l. No	Parameters /Source of variation	Temperature F value	P value	Salinity F value	P value	Temp x Salinity F value	P value
1.	Size at Birth (µm)	0.074	0.79	0.107	0.75	0.012	0.91
2.	Size at first egg production (µm)	6.407	0.04	3.775	0.09	1.26	0.29
3.	Maximum size(µm)	3.05	0.12	3.561	0.01**	1.282	0.29
4.	Juvenile period (days)	10.83	0.01**	29.36	0.01**	3.65	0.09
5.	Time taken from neonate till last egg production (days)	8.554	0.01**	55.14	0.00**	1.55	0.25
6.	Egg hatching time (hrs)	0.60	0.46	1.67	0.23	0.67	0.80
7.	Total number of eggs produced	90.76	0.00**	229.5	0.01**	0.220	0.65
8.	Maximum number of eggs carried at one time	12.25	0.00**	42.25	0.00**	0.250	0.63
9.	Reproductive period (days)	13.97	0.01**	81.64	0.00**	2.832	0.13
10.	Post reproductive period (days)	279.5	0.00**	263.05	0.00**	73.39	0.00**
11.	Lifespan (days)	252.7	0.00**	13.39	0.01**	7.225	0.00**

* $p<0.05$; **$p<0.01$

Table 46a: Mean and SD of 11 life table parameters of *B. plicatilis* at different salinities at room temperature (28-30°C)

SL No:	Parameters/ salinity	0.5ppt Mean ± SD	5 ppt Mean ± SD	10 ppt Mean ± SD	15 ppt Mean ± SD	25 ppt Mean ± SD	35 ppt Mean ± SD
1.	Size at birth(µm)	148.69 ± 3.91	148.92 ±0.21	146.46 ±0.65	146.31 ±1.19	146.06 ±1.69	145.64 ±0.85
2.	Size at first egg production (µm)	188.67 ±3.28	189.92 ±2.15	186.87 ±0.33	186.74 ±1.48	186.03 ±1.97	186.11 ±0.48
3.	Maximum size(µm)	261.94 ±2.91	262.74 ±3.79	259.8 ±5.62	258.83 ±7.39	257.47 ±7.99	257.10 ±9.62
4.	Juvenile period(days)	0.583 ±0.01	0.54 ±0.02	0.66 ±0.02	0.84 ±0.02	0.98 ±0.08	1.25 ±0.03
5.	Egg hatching time(days)	3.26 ±0.03	3.13 ±0.02	3.48 ±0.05	3.96 ±0.07	3.99 ±0.22	4.29 ±0.06
6.	Time taken from neonate till last egg production (days)	4.73 ±0.03	4.84 ±0.06	4.62 ±0.19	3.83 ±0.10	3.302 ±0.23	3.19 ±0.15
7.	Reproductive period (days)	4.16 ±0.03	4.29 ±0.06	4.11 ±0.19	3.23 ±0.11	2.47 ±0.23	2.233 ±0.202
8.	Post reproductive period(days)	0.98 ±0.05	0.94 ±0.04	0.89 ±0.10	1.44 ±0.09	0.87 ±0.23	0.74 ±0.22
9.	Total number of eggs produced	18±3	18±2	13±2	8±1	6±2	5±1
10.	Maximum number of eggs carried at one time	2 ± 1	3±1	2±1	2±1	1±1	1±0
11.	Lifespan (days)	5.72 ±0.06	5.77 ±0.11	5.52 ±0.02	5.27 ±0.02	4.17 ±0.04	3.89 ±0.18

Table 46b: Mean and SD of 11 life table parameters of *B. plicatilis* at different salinities at thermostat temperature (35-37°C)

SNo	Parameters/ salinity	0.5ppt Mean ± SD	5 ppt Mean ± SD	10 ppt Mean ± SD	15 ppt Mean ± SD	25 ppt Mean ± SD	35 ppt Mean ± SD
1.	Size at birth(µm)	144.78 ± 2.39	144.82 ±1.69	143.91 ±2.0	143.17 ±3.57	142.83 ±3.45	142.56 ±1.87
2.	Size at first egg production (µm)	186.44 ±3.72	185.79 ±0.32	185.34 ±1.68	182.57 ±1.71	181.06 ±3.94	180.34 ±1.11
3.	Maximum size(µm)	256.93 ±9.63	256.93 ±9.51	253.54 ±10.32	248.92 ±10.28	247.83 ±10.34	239.99 ±5.72
4.	Juvenile period(days)	0.51 ±0.03	0.47 ±0.02	0.60 ±0.02	0.70 ±0.01	0.76 ±0.03	0.99 ±0.03
5.	Egg hatching time(days)	2.93 ±0.17	2.77 ±0.09	3.01 ±0.09	3.37 ±0.05	3.57 ±0.07	3.85 ±0.03
6.	Time taken from neonate till last egg production (days)	4.12 ±0.09	4.67 ±0.06	2.81 ±0.16	2.83 ±0.04	2.72 ±0.11	2.55 ±0.07
7.	Reproductive period (days)	3.46 ±0.09	4.2 ±0.07	2.11 ±0.17	1.71 ±0.07	1.96 ±0.19	1.56 ±0.07
8.	Post reproductive period(days)	0.91 ±0.10	0.913 ±0.06	1.05 ±0.09	0.526 ±0.03	0.52 ±0.14	0.63 ±0.08
9.	Total number of eggs produced	16±2	14±1	10±3	7±1	5±1	4±1
10.	Maximum number of eggs carried at one time	3±1	2±1	1±1	1±1	1±1	1±0
11.	Lifespan (days)	5.03 ±0.04	5.58 ±0.02	3.92 ±0.02	3.35 ±0.03	3.29 ±0.06	3.182 ±0.06

Table 46c: Result of two-way ANOVA (F and P values only) of life table parameters of *Brachionus plicatilis* in relation to salinity and temperature

S l. No	Parameters /Source of variation	Temperature F value	P value	Salinity F value	P value	Temp x Salinity F value	P value
1.	Size at Birth (µm)	4.56	0.00**	67.12	0.00**	0.238	0.95
2.	Size at First egg production (µm)	15.01	0.00**	120.26	0.00**	5.99	0.00**
3.	Maximum size(µm)	9.58	0.00**	23.56	0.00**	0.333	0.89
4.	Juvenile period (days)	401.221	0.00**	865.85	0.00**	21.19	0.00**
5.	Time taken from neonate till last egg production (days)	1787.6	0.00**	520.9	0.00**	118.9	0.00**
6.	Egg hatching time (hrs)	603.72	0.00**	855.83	0.00**	3.169	0.10
7.	Total number of eggs produced	263.84	0.00**	76.52	0.00**	8.18	0.00**
8.	Maximum number of eggs carried at one time	23.84	0.00**	4.69	0.00**	1.72	0.09
9.	Reproductive period (Days)	60.12	0.00**	1281.4	0.00**	3.536	0.05*
10.	Post reproductive period (days)	9.856	0.02*	52.71	0.00**	18.08	0.00**
11.	Life span (days)	212.6	0.00**	4305.9	0.00**	67.07	0.00**

* $p<0.05$; ** $p<0.01$

Table 47a: Mean and SD of 11 life table parameters of *B. murray* at different salinities at room temperature (28-30°C)

SL No:	Parameters/ salinity	0.5 ppt Mean ± SD	5 ppt Mean ±SD	10 ppt Mean ±SD	15 ppt Mean ±SD	25 ppt Mean ±SD	35ppt Mean ±SD
1.	Size at birth (µm)	137.06 ± 4.6	137.33 ±5.2	137.40 ±2.1	136.72 ±2.9	136.70 ±2.9	136.11 ±2.2
2.	Size at first egg production (µm)	171.70 ±2.8	172.80 ±3.8	172.80 ±1.8	172.70 ±3.3	172.30 ±2.2	171.20 ±1.8
3.	Maximum size (µm)	221.04 ±2.2	221.60 ±3.5	223.5 ±2.6	221.7 ±3.2	220.9 ±4.3	219.4 ±5.4
4.	Juvenile period (days)	0.68 ±0.18	0.69 ±0.60	0.57 ±0.01.	0.69 ±0.01	0.97 ±0.02	1.09 ±0.05
5.	Egg hatching time (days)	3.72 ±0.02	3.87 ±0.24	2.72 ±0.01	2.87 ±0.03	2.89 ±0.09	3.12 ±0.11
6.	Time taken from neonate till last egg production (days)	3.7 ±0.14	3.87 ±0.18	4.89 ±0.38	4.04 ±0.19	3.24 ±0.29	2.81 ±0.42
7.	Reproductive period (days)	3.09 ±0.34	3.23 ±0.24	4.22 ±0.32	3.4±0.21	2.06 ±0.38	1.9±0.53
8.	Post reproductive period (days)	0.39 ±0.27	0.43 ±0.26	0.91 ±0.43	0.44 ±0.16	0.59 ±0.32	0.49 ±0.34
9.	Total number of eggs produced	20±1	22±2	24±2	16±1	8±1	5±1
10.	Maximum number of eggs carried at one time	3 ± 1	3±1	3±1	2±1	1±1	1±0
11.	Lifespan (days)	4.12 ±0.15	4.31 ±0.24	5.65 ±0.27	4.47 ±0.13	3.62 ±0.11	3.37 ±0.36

Table 47b: Mean and SD of 11 life table parameters of *B. murray* at different salinities at thermostat temperature (35-37°C)

SNo	Parameters/ salinity	0.5 ppt Mean ± SD	5ppt Mean ±SD	10ppt Mean ±SD	15ppt Mean ±SD	25ppt Mean ±SD	35ppt Mean ±SD
1.	Size at birth (µm)	137.42 ± 2.9	136.7 ±3.1	136.95 ±2.9	137.1 ±3.3	136.51 ±3.14	132.9 ±3.9
2.	Size at first egg production (µm)	171.20 ±1.84	171.7 ±2.4	172.09 ±2.2	171.96 ±2.5	171.04 ±2.8	171.01 ±2.97
3.	Maximum size (µm)	220.25 ±3.3	221.02 ±2.22	222.98 ±2.4	220.54 ±7.5	219.25 ±3.93	210.9 ±6.73
4.	Juvenile period (days)	0.63 ±0.03	0.61 ±0.20	0.53 ±0.2	0.68 ±0.03	0.89 ±0.03	0.98 ±0.01
5.	Egg hatching time (days)	2.93 ±0.11	2.88 ±0.11	2.5 ±0.06	2.7 ±0.07	2.84 ±0.02	2.97 ±0.01
6.	Time taken from neonate till last egg production (days)	3.24 ±0.29	3.13 ±0.18	4.59 ±0.42	3.66 ±0.47	3.07 ±0.23	2.81 ±0.41
7.	Reproductive period (days)	2.6 ±0.29	2.57 ±0.38	3.87 ±0.49	3.05 ±0.52	2.19 ±0.28	1.99 ±0.53
8.	Post reproductive period days)	0.34 ±0.28	0.23 ±0.24	0.92 ±0.47	0.52 ±0.39	0.37 ±0.24	0.42 ±0.32
9.	Total number of eggs produced	18±2	20±1	24±1	13±2	8±2	4±1
10.	Maximum number of eggs carried at one time	3 ± 1	3±1	3±1	2±1	1±1	1±0
11.	Lifespan (days)	3.61 ±0.15	3.34 ±0.10	5.5 ±0.25	4.21 ±0.13	3.33 ±0.36	3.24 ±0.32

Table 47c: Result of two-way ANOVA (F and P values only) of life table parameters of *Brachionus murray* in relation to salinity and temperature

S l. No	Parameters /Source of variation	Temperature F value	P value	Salinity F value	P value	Temp x Salinity F value	P value
1.	Size at Birth (µm)	1.248	0.29	1.236	0.27	1.131	0.35
2.	Size at first egg production (µm)	2.638	0.37	9.338	0.89	1.154	0.34
3.	Maximum size(µm)	7.69	0.00**	8.104	0.05*	2.44	0.04
4.	Juvenile period (days)	206.8	0.00**	34.01	0.00**	1.907	0.01
5.	Time taken from neonate till last egg production (days)	77.52	0.00**	21.08	0.00**	3.34	0.08
6.	Egg hatching time (hrs)	92.78	0.00**	13.708	0.00**	4.79	0.00**
7.	Total number of eggs produced	417.7	0.00**	15.04	0.00**	3.91	0.03*
8.	Maximum number of eggs carried at one time	8.33	0.05*	50.4	0.00**	3.58	0.05*
9.	Reproductive period (Days)	103.8	0.00**	468.42	0.00**	135.35	0.00**
10.	Post reproductive period (days)	7.843	0.00**	0.134	0.72	0.667	0.65
11.	Life span (days)	545.7	0.00**	161.15	0.00**	24.27	0.00**

* $p<0.05$; ** $p<0.01$

Table 48a: Mean and SD of 11 life table parameters of *B. rotundiformis* at different salinities at room temperature (28-30°C)

SL No:	Parameters/ salinity	2ppt Mean ± SD	5 ppt Mean ± SD	10 ppt Mean ± SD	15ppt Mean ± SD	25ppt Mean ± SD	35ppt Mean ± SD
1.	Size at birth(µm)	98.83 ±9.57	98.83 ±7.57	97.80 ±9.7	96.73 ±7.90	97.33 ±6.93	94.50 ±6.71
2.	Size at first egg production (µm)	118.32 ±10.94	118.12 ±9.48	117.51 ±10.3	117.32 ±10.4	116.98 ±9.34	109.4 ±9.83
3.	Maximum size(µm)	170.06 ±6.08	172.70 ±6.23	172.83 ±3.23	173.83 ±4.73	171.83 ±4.98	171.32 ±4.88
4.	Juvenile period(days)	0.93 ±0.03	0.92 ±0.04	0.87 ±0.12	0.61 ±0.05	0.83 ±0.08	0.98 ±0.03
5.	Egg hatching time(days)	3.73 ±0.51	3.28 ±0.16	3.76 ±0.27	2.84 ±0.11	3.08 ±0.11	3.89 ±0.51
6.	Time taken from neonate till last egg production (days)	2.98 ±0.13	3.01 ±0.18	3.14 ±0.51	5.13 ±0.16	3.03 ±0.27	2.78 ±0.27
7.	Reproductive period (days)	2.05 ±0.41	2.18 ±0.43	3.34 ±0.44	4.12 ±0.14	3.93 ±0.43	3.38 ±0.18
8.	Post reproductive period(days)	0.27 ±0.11	0.47 ±0.33	0.65 ±0.13	1.35 ±0.72	0.06 ±0.12	0.60 ±0.13
9.	Total number of eggs produced	10±2	12±3	18±2	22±3	16±3	10±2
10.	Maximum number of eggs carried at one time	2±1	2±1	2±2	4±1	2±2	2±1
11.	Lifespan (days)	3.25 ±0.50	3.48 ±0.60	3.52 ±0.71	5.68 ±0.35	3.99 ±0.46	3.98 ±0.78

Table 48b: Mean and SD of 11 life table parameters of *B. rotundiformis* at different salinities at thermostat temperature (35-37°C)

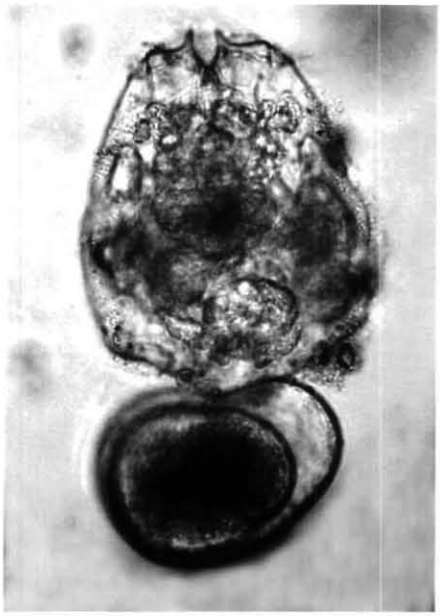
SL No:	Parameters/ salinity	2ppt Mean ± SD	5ppt Mean ± SD	10ppt Mean ± SD	15ppt Mean ± SD	25ppt Mean ± SD	35ppt Mean ± SD
1.	Size at birth(µm)	96.68 ±6.28	96.54 ±7.67	95.4 ±6.71	96.33 ±5.71	94.3 ±8.28	91.80 ±6.95
2.	Size at first egg production (µm)	118.41 ±9.68	118.59 ±9.69	118.59 ±9.28	117.80 ±9.43	116.41 ±9.69	115.3 ±4.38
3.	Maximum size(µm)	174.91 ±4.4	173.31 ±6.4	171.94 ±5.4	176.06 ±9.43	172.08 ±4.4	171.13 ±6.9
4.	Juvenile period(days)	0.83 ±0.08	0.77 ±0.67	0.67 ±0.08	0.45 ±0.05	0.68 ±0.08	0.88 ±0.03
5.	Egg hatching time(days)	2.98 ±0.03	3.01 ±0.02	2.99 ±0.02	3.00 ±0.03	2.76 ±0.02	3.22 ±0.01
6.	Time taken from neonate till last egg production (days)	3.01 ±0.41	3.28 ±0.28	3.35 ±0.22	4.23 ±0.28	4.37 ±0.39	2.12 ±0.24
7.	Reproductive period (days)	2.18 ±0.11	2.61 ±0.14	2.44 ±0.71	4.68 ±0.63	2.44 ±0.23	1.24 ±0.33
8.	Post reproductive period(days)	0.11 ±0.12	0.28 ±0.11	0.63 ±0.06	1.15 ±0.70	0.66 ±0.12	1.16 ±0.09
9.	Total number of eggs produced	7±1	7±1	9±1	15±2	6±2	5±1
10.	Maximum number of eggs carried at one time	1±0	1±1	2±1	3±1	2±1	1±1
11.	Lifespan (days)	3.25 ±0.18	3.48 ±0.44	3.42 ±0.43	5.67 ±0.38	3.93 ±0.32	2.28 ±0.43

Table 48c: Result of two-way ANOVA (F and P values only) of life table parameters of *Brachionus rotundiformis* in relation to salinity and temperature

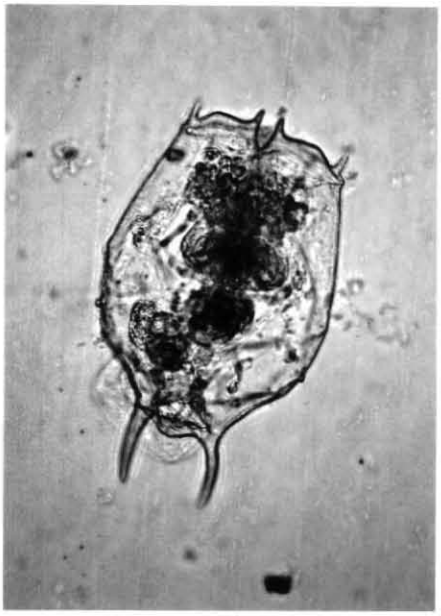
Sl. No	Parameters /Source of variation	Temperature F value	P value	Salinity F value	P value	Temp x Salinity F value	P value
1.	Size at Birth (µm)	19.80	0.00**	33.79	0.000**	1.34	0.98
2.	Size at first egg production (µm)	1.349	0.72	4.731	0.050	1. 54	0.34
3.	Maximum size(µm)	23.14	0.00**	0.00	1.00	1.31	0.48
4.	Juvenile period (days)	58.55	0.00**	47.72	0.000**	3.27	0.03*
5.	Time taken from neonate till last egg production (days)	24.27	0.00**	34.01	0.000**	3.45	0.04*
6.	Egg hatching time (hrs)	4.93	0.04*	5.72	0.001	1.131	0.10
7.	Total number of eggs produced	14.08	0.00**	72.43	0.000**	0.48	0.83
8.	Maximum number of eggs carried at one time	1.04	0.45	5.67	0.05*	0.72	0.62
9.	Reproductive period (Days)	44.71	0.00**	24.63	0.00**	0.56	0.79
10.	Post reproductive period (days)	0.94	0.98	21.45	0.00**	3.72	0.00**
11.	Lifespan (days)	36.09	0.00**	240.7	0.00**	0.73	0.43

* $p < 0.05$; ** $p < 0.01$

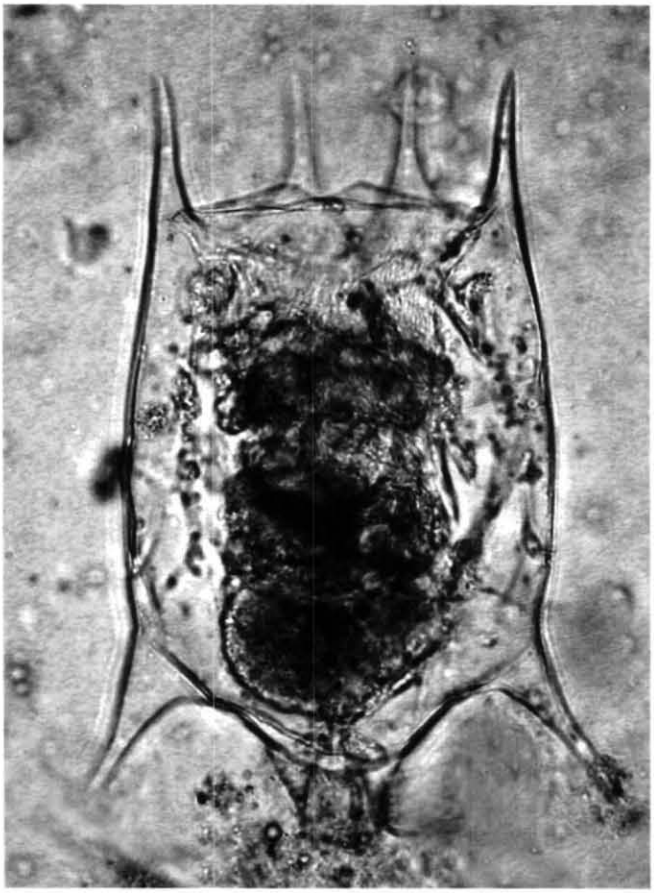
PLATE 3



Brachionus angularis

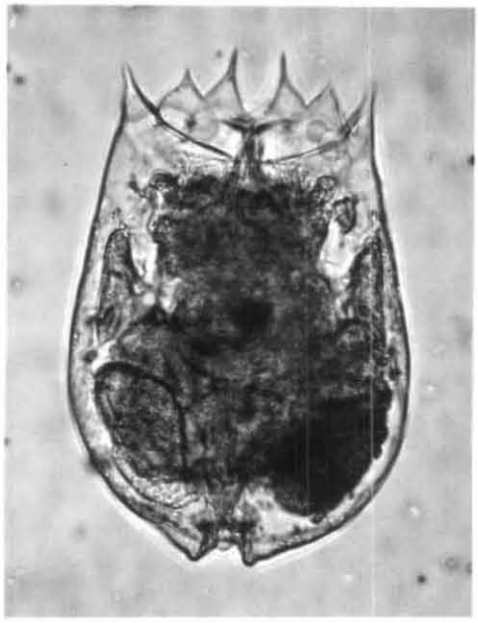


Brachionus caudatus

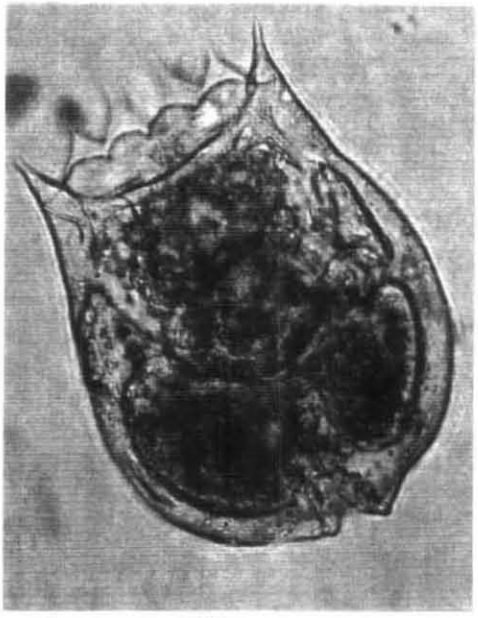


Brachionus calyciflorus

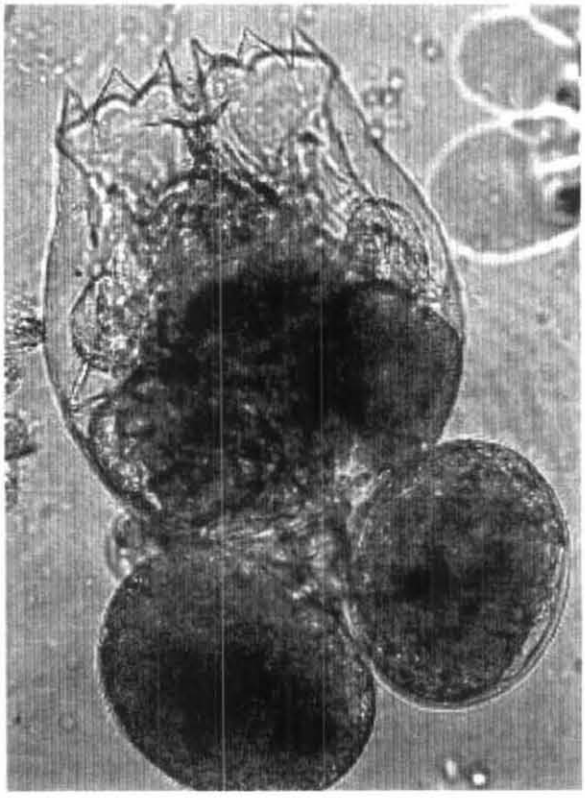
PLATE 4



Brachionus murray (S type)

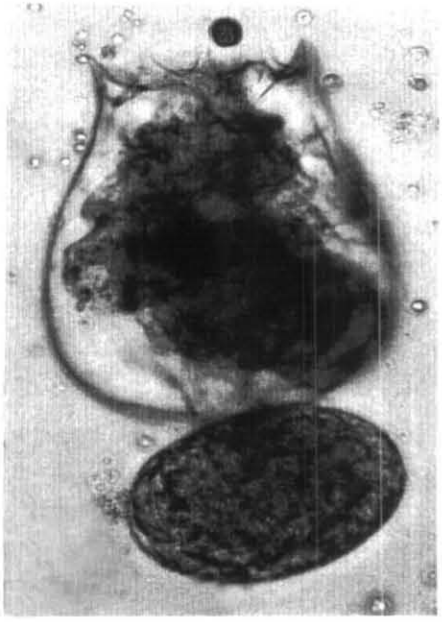


Brachionus murray with scalloped pectoral margin

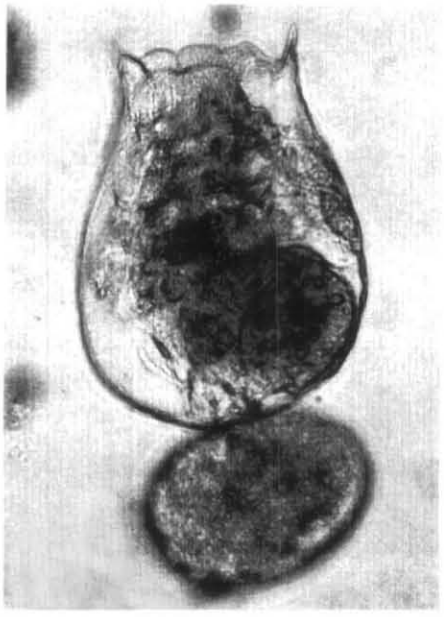


Brachionus plicatilis (L type)

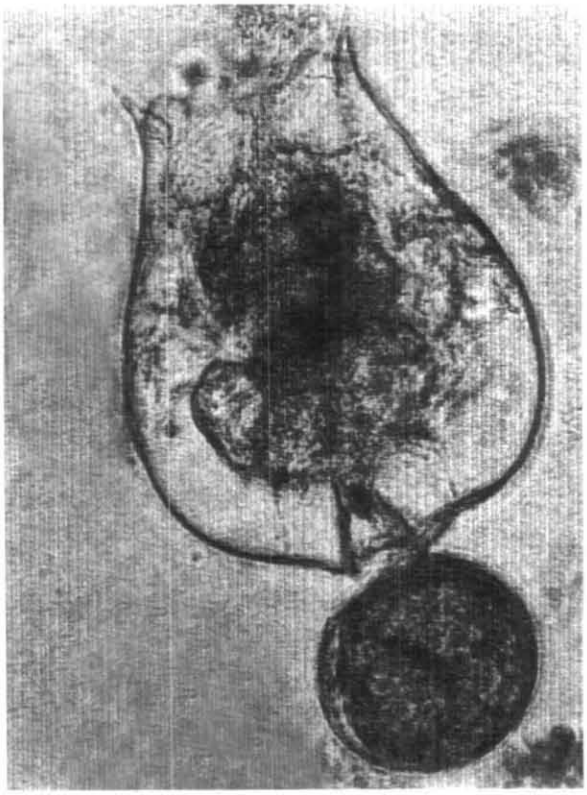
PLATE 5



Brachionus rotundiformis
(ss type)



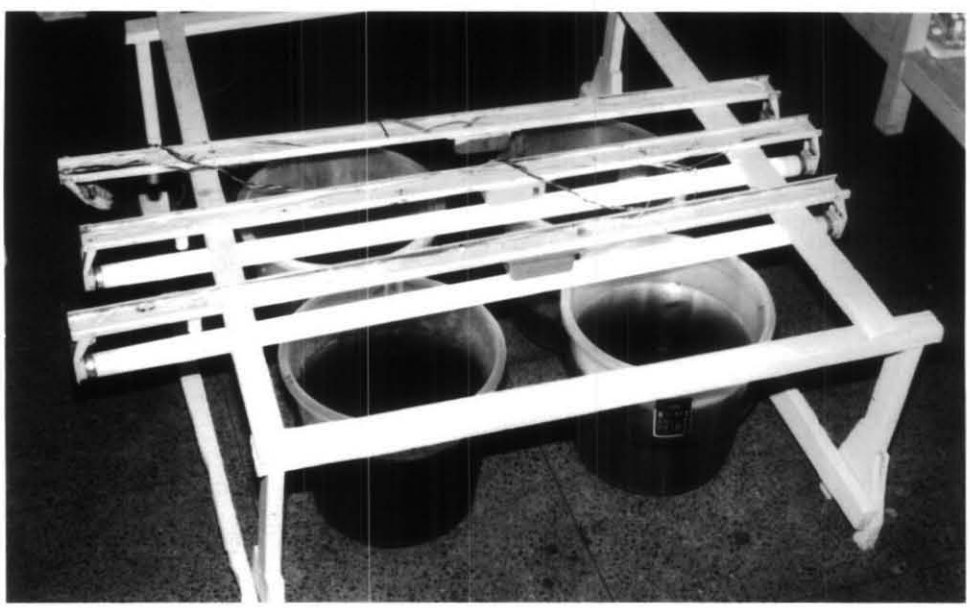
B. rotundiformis
(with elevated lateral pectoral margin)



Brachionus rotundiformis

PLATE 6

Microalgae stock culture



Microalgae mass culture (indoor culture)

PLATE 7

Figs.1&6: A view of *B. murray* mass culture (5 x & 10 x)

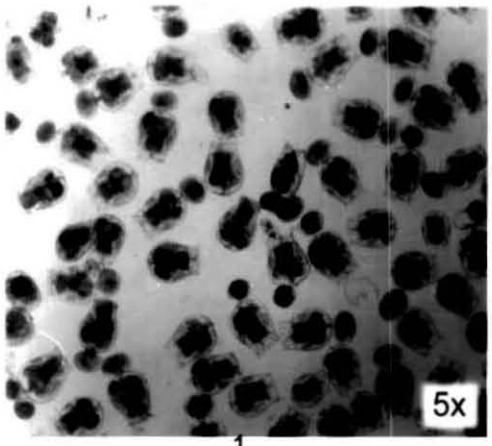
Figs. 2&3: A view of *Brachionus plicatilis* mass culture (5 x & 10 x)

Figs.4&5: A view of *B. rotundiformis* mass culture (10 x & 5 x)

Fig. 7: A view of *B. caudatus* mass culture (10 x)

Fig. 8: A view of *B. angularis* mass culture (10 x)

PLATE 7



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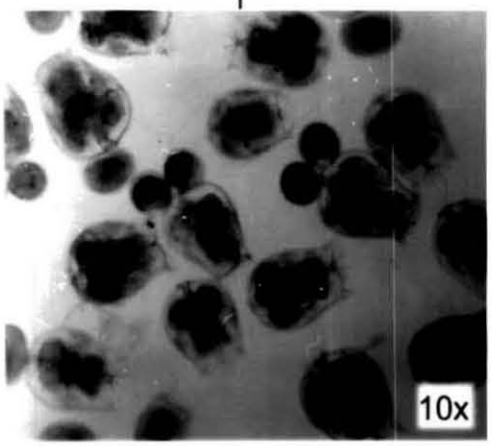

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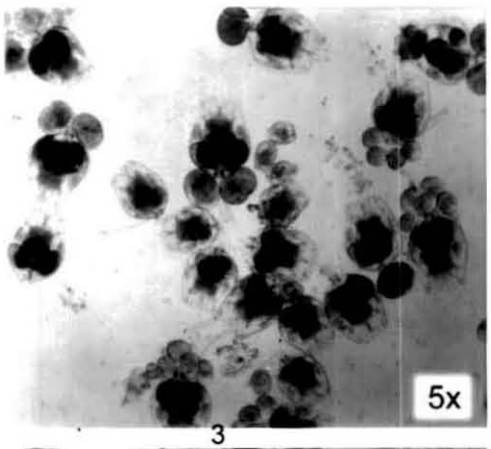

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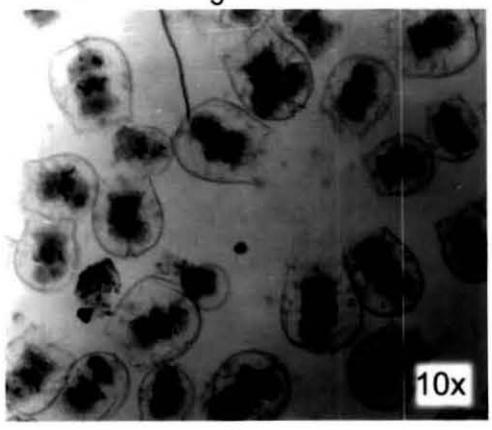

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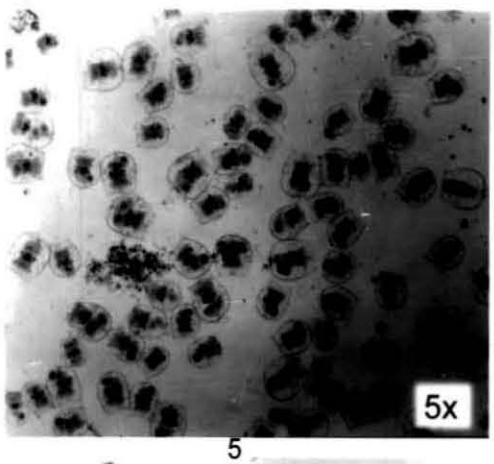

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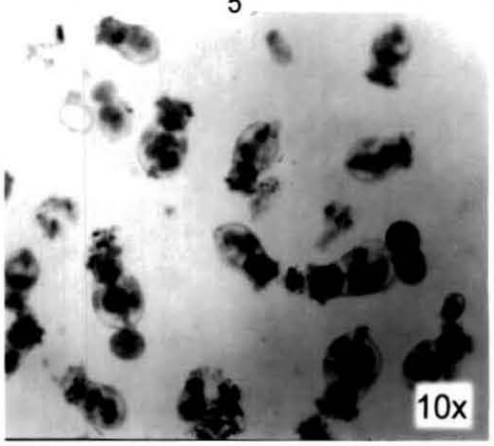

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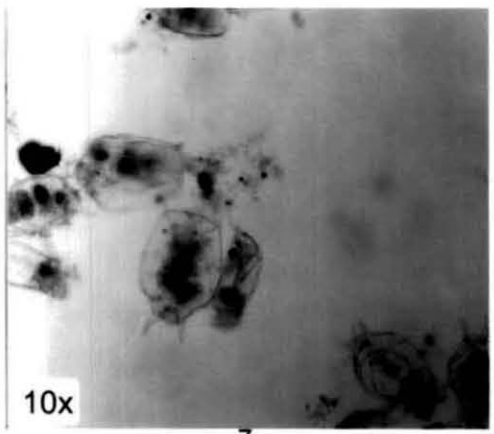

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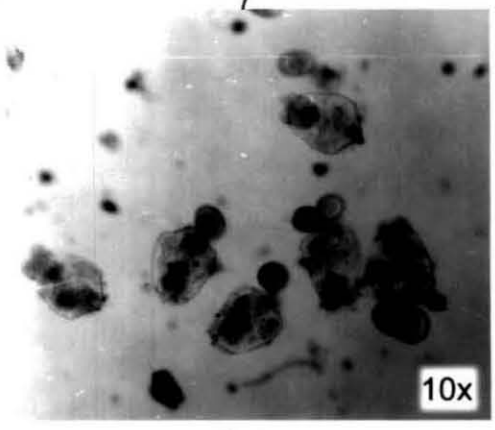

8

CHAPTER 5

EVALUATION OF ROTIFERS OF DIFFERENT SIZE GROUPS FOR FINFISH LARVICULTURE

INTRODUCTION

Feed is one of the key factors essential to the success of aquatic animal culture. It directly affects survival and development of larvae. Because live feeds have all the advantages such as not contaminating the culture water, easy digestion and assimilation, promoting high growth rates and having a higher nutritional value than other feeds, their culture is the principal means of promoting food for larvae. Furthermore, as aquaculture has progressed, the scope for culture of marine and freshwater finfish and shellfish larvae and their feeds have vastly expanded and become more important. Research into the development and culture of food organisms must be expanded rapidly to satisfy the growing demands of larviculture.

Nutrient requirements of all animals vary throughout their life-cycle. The changes that occur in the morphology and physiology of animals between hatching and maturity lead to a number of important variations in feeding and nutritional requirements through the larval, fingerling and adult stage. The initial nourishment to the developing fish larva is obtained from the egg yolk. When the yolk reserve has been completely utilized the larval feeding capabilities are developed and hence at this stage their survival is entirely dependent on the availability and quality of food in sufficient quantities. Hence, the transition from an endogenous to an exogenous food supply, which marks the onset of the larval stage, is one of the most critical phases of the life cycle and is the period when much of the mortality occurs in the hatchery. The newly hatched larvae of only a few species of fish carry big yolksacs, which provide enough endogenous food for the first weeks of their development. After this period the larvae are already sufficiently developed and of a size to accept formulated feeds readily. Most of the marine fish larvae and freshwater ornamental fish larvae are usually small at hatching time (Theilacker and Dorsey, 1980; Lim and Wong, 1997), and except

for a few species, their size ranges between 2 mm and 7mm. These larvae have very limited yolk reserves and have to resort to exogenous feeding eventhough they have small mouth and primitive digestive system. Therefore, the food offered to them must meet their nutritional requirements for optimization of survival and growth. Thus, nutrition at this early stage is very critical and an artificial feed catering to the nutritional requirements at this stage of the larvae is yet to be formulated and hence live food organisms are still used as a successful diet for the developing larvae in the larviculture industry.

Among the live feeds, rotifers are considered to be an excellent food source for newly hatched fish larvae because of its small size, relatively slow motility, high caloric value and the possibility of artificially manipulating its nutritional qualities. Since its initial application as a live food organism for the larval red seabream (*Pagrus major*), the haline rotifer *Brachionus plicatilis* has become a widely used food organism in the larval culture of over sixty marine fish and eighteen crustacean species throughout the world (Fujita, 1979; Lubzens *et al.*, 1989). This rotifer, once considered as a pest in Japanese eel culture ponds (Hirata, 1979, 1980), is now indispensable in raising fish larvae of several marine and freshwater species of economic value such as grey mullet (*Mugil cephalus*), sole (*Solea solea*), gilthead seabream (*Sparus aurata*), European seabass (*Dicentrarchus labrax*), Asian seabass (*Lates calcarifer*), turbot (*Scophthalmus maximus*), flounder (*Paralichthys olivaceus*), milkfish (*Chanos chanos*), groupers (*Epinephelus striatus, E. tauvina, E. suillus*), mahimahi (*Coryphaena hippurus*), black porgy (*Acanthopagius schlegeli*), pacific halibut (*Hippoglossus stenolepis*), cod (*Gadus morhua*), red porgy (*Pagrus pagrus*), ayu (*Plecoglossus altivelis*), yellow tail snapper (*Ocyurus chrysurus*), cyprinids (*Cyprinus carpio*)and marine ornamental fish such as clown fish , *Amphiprion chrysogaster* (= *sebae*) etc., (Nash *et al.*, 1974; Grin, 1975; Hussain and Hiquchi, 1980; Juario *et al.*, 1984; Witt *et al.*, 1984; Tandler and Helps, 1985; Fukusho *et al.*, 1985; Dendrinos and Thorpe, 1987; Villegas, 1990; Tamaru *et al.*, 1991; Parazo *et al.*, 1991; Kraul,

1993; Lim, 1993; Liu *et al.*, 1993; Barlow *et al.*, 1993; Tucker, 1994; Leu, 1997; Kolios *et al.*, 1997; Turano *et al.*, 2000; Nikos *et al.*, 2000; Gopakumar *et al.*, 2000).

However, the potential application of rotifers in freshwater finfish larviculture has not been fully exploited, and so far it was restricted to only a few freshwater food fish species and ornamental fish species such as sunshine bass (*Morone chrysops*), striped bass (*M. saxatilis*), Dwarf gourami (*Colisa lalia*), Brown discus, *Symphysodon aequifasciata axelrodi* and three spotted gourami (*Trichogaster trichopterus*) (Snow *et al.*, 1980; Awaiss, 1991; Awaiss *et al.*, 1992; Ludwig, 1994, 2000; Lim and Wong, 1997; Gopakumar, 1998).

Lim and Wong (1996) reported that due to lack of small sized zooplankters, the breeding of the freshwater fish to-date has been restricted to species with relatively large larvae/ fry from most of the aquacutlurally advanced nations. The common live larval food used in commercial larviculture of freshwater fish is limited mainly to macro-zooplankton such as *Moina, Daphnia* and *Artemia* nauplii. Fish larvae with a mouth size too small to ingest these at initial feeding are either not reared successfully or have to be fed inert food such as milk powder, egg yolk and powder feeds or on induced plankton blooms.

Lubzens *et al.* (1989) listed five requirements of rotifers as a starter food for the optimization of growth and survival of fish larvae. They are; a) the size; b) the distribution and concentration of rotifers in the larval tanks; c) the total amount available; d) digestibility and absorption; and e) nutritional quality. The size of the prey eaten by the fish larvae is a function of the larval width of the mouth. Within a fish species, mouth width is related to length, but it varies greatly between species (Beyer, 1980; Hunter, 1980; Hunter and Kimbrell, 1980). Although mouth width limits the maximum prey size, in nature the mean diameter of the prey consumed by fish larvae was only 38% of their mouth width (Hunter,

1980). Fish larvae tend to increase both quantity and size range of the particles upon which they feed throughout their ontogeny. The increase in the number of food items ingested daily by fish larvae is an exponential function of larval age (Lasker *et al.*, 1970; Stepiens, 1976; Hunter, 1980; Hunter and Kimbrell, 1980) or length (Okauchi *et al.*, 1980; Barahona-Fernades and Conan, 1981; Minkoff, 1987). Beyer and Laurence (1981) concluded that as larvae reach certain sizes, the energetic cost of each attack on prey exceeds the gain from ingesting smaller food particles. This size depends upon the larva's metabolic requirements, which are imposed both genetically and environmentally. The effect of age of gilthead seabream larvae (*Sparus aurata*) on their preference for rotifer strains of different sizes was examined in the laboratory (Helps, 1982). In this study, larvae showed a clear age effect on their feeding preference of different size rotifers. Young larvae, upto 85 hours after hatching, preferred small rotifers (30 - 70 µm) and avoided feeding on large rotifers (90 –100 µm), while in older larvae (160 hrs) the pattern was reversed. Concomitant to the increase in feeding rates, the growing larvae tend to require larger food particles. This factor had led to the use of different rotifer strain sizes in rearing of fish larvae and they allow different larval stages to select prey of the most effective size (Fukusho, 1983; Korunuma and Fukusho, 1987; Minkoff, 1987).

The distribution of rotifers in the water column of larval tanks depends mainly on the salinity of the rearing medium. Exposing rotifers to sudden changes in salinity will result in their adhesion to the bottom or sides of containers (Gatesoupe and Luquet, 1981), making them unavailable to the larvae. Other factors affecting the distribution of rotifers are oxygen and ammonia levels which affect the swimming speed (Epp and Winston, 1978; Snell *et al.*, 1987) and the type of food offered to rotifers.

The nutrition of fish larvae depends primarily on the probability of encounter between the food and the larvae as well as its suitability in terms of

size and nutrient composition (Fukusho and Okauchi, 1982; Fukusho *et al.*, 1985; Hagiwara *et al.*, 1996). The probability of encounter between the larvae and the rotifer depends on concentration (Hunter, 1980; Theilacker and Dorsey, 1980). The optimal food concentration depends on the life stage and temperature. First feeding larvae have relatively slow swimming speeds (Fukuhara, 1983) and low capture success at onset of feeding (2 - 10%) (Hunter, 1980), so they may require a high rotifer concentration. Upto a rotifer concentration of 10/ml, a direct relationship between survival, growth and food concentration was shown in gilthead seabream (*Sparus aurata*) and in bream (*Archosargus rhomboidalis*) and beyond this concentration, a sharp drop in both survival and growth of the larvae was observed (Tandler and Sherman, 1981; Peguin, 1984; Dowd and Houde, 1980). The negative effect of elevated rotifer concentrations on growth of fish larvae was associated with reduced efficiency of the digestive process at high rotifer concentrations (Tandler and Mason, 1984; Boehlert and Yoklavich, 1984). The larval density in the culture tanks also affects the growth of the larvae (Okamoto, 1969; Chona *et al.*, 1998). Larvae depend primarily on vision to find their food, as a result of the pure cone retina found in the majority of fish larvae (Blaxter and Staines, 1970; Blaxter, 1975). Photoperiod, light intensity and color of background of rearing containers are therefore of paramount importance for their hunting success. The effect of photoperiod in combination with rotifer concentration is intimately related to the probability of encounter between the larvae and its food (Dowd and Houde, 1980; Peguin, 1984; Barahona-Fernades, 1979).

The assimilation of ingested rotifers by fish larvae has been shown to be very rapid (Govoni *et al.*, 1982). The gross growth efficiency, which is the proportion of the ingested food in growth, has been evaluated for larvae feeding on rotifers and in general it ranged from 20 - 60% (Minkoff, 1987). The nutritional value of rotifers to larvae depends on their dry weight, caloric content and biochemical composition (Doohan, 1973; Tandler and Mason. 1984; Theilacker

and Kimball, 1984; Minkoff, 1987). Scott and Baynes (1978) have found protein in the range of 50 - 58% of the rotifer's dry weight and lipids usually range from 9 - 23% of the dry weight (Minkoff, 1987). Rotifers, which are raised on baker's yeast alone, are inadequate as food for marine fish larvae due to their lack of n - 3 series (HUFA) fatty acids. However, the dietary HUFA requirements for most marine fish larvae have not yet been determined in a way that will differentiate between a need for either 20:5 n-3 or 22:6 n-3 or both (Lubzens *et al.*, 1989).

Thus among the live food organisms, rotifers possess several characteristics such as small size, slow swimming speed and high caloric value that make them attractive as live food in larviculture. Furthermore, a suitable inert feed has not yet been formulated and at present micro-diets cannot completely replace rotifers as the first feed for fish larvae of small size. Therefore, culture of rotifers takes the place as the principal mode of promoting suitable food for various finfish and shellfish larvae. Hence the present study was undertaken to evaluate the following objectives:

A). to assess the suitability of the rotifers namely *Brachionus angularis*, *B. caudatus*, *B. plicatilis* and *B. calyciflorus*, for use in the larviculture of freshwater ornamental fish, pearl gourami (*Trichogaster leeri*).

B). to compare the performance of larvae with traditional methods of feeding.

C). to study the effect of age of larvae on their preference for rotifers of different size and

D). to study the feeding behavior of the early and advanced larvae.

The same methodology can be adopted to evaluate the suitability and the effect of age of marine fish larvae on their preference for haline rotifers namely *Brachionus rotundiformis* 'ss' *type* (length: 98 – 171 µm, width: 80 – 125 µm), *B. rotundiformis* 'S' type (length: 136 - 212 µm, width: 100 - 144 µm) and *B. plicatilis*

(length: 145 - 250 µm, width: 156 - 175 µm) of different sizes. Because of the unavailability of any other marine or brackishwater fish larvae during the period of study, the pearl gourami larvae was selected as a test animal to show that the significance of initial prey size on the survival and growth of the finfish larvae.

Pearl gourami (*Trichogaster leeri*) is the most popular gourami in the pet market. The fish is peaceful and hardy (Axelrod and Sweeney, 1992; Mayadevi, 1997). *T. leeri* are bubble nest builder, perennial breeder and exhibit fascinating breeding behaviour. The eggs are small and the embryonic development is rapid and is completed within 24 hrs. This species was selected as a test animal for the present study because of its small larvae. The newly hatched larvae measure only 2.72 ± 0.02 mm and cannot ingest macro-zooplankton at their initial feeding. Traditionally, gourami larvae are raised in extensive culture in large outdoor ponds and fed egg-yolk particles followed by macro-zooplankton especially *Moina* or *Artemia* nauplii.

Among the *Brachionus* species the suitability of *B. calyciflorus* as a first feed for dwarf gourami and brown discus larvae was studied by Lim and Wong (1997). Similarly, Gopakumar (1998) studied the growth and survival of three spotted gourami larvae fed with *B. plicatilis* at different feed concentrations. However, so far no information is available on the use of rotifers *B. angularis*, *B. caudatus* and *B. calyciflorus* as live feed in the finfish larviculture of either food fish or ornamental fish species from India.

MATERIAL AND METHODS

Rotifer culture: The stock of four rotifer species namely *Brachionus angularis*, *B. caudatus*, *B. plicatilis* and *B. calyciflorus* were isolated from local waters and maintained in the laboratory over a year. Rotifer mass culture was

performed using a batch culture system in outdoor 250 l FRP tanks at 28 - 32°C. They were cultured solely on microalgae, *Chlorella ellipsoidea* at around 2 - 3 million cells/ml. The stocking density of rotifer was 20 – 30 /ml and total harvest was conducted after 4 - 5 days at 100 - 150 /ml.

Pearl gourami larviculture experiment: The experiment was conducted in 20 l glass aquarium tanks at temperature of 28 - 32°C. Larvae of pearl gourami were obtained by natural spawning of fish of matured male and female pairs in an aquarium tank. The eggs hatched in 24 hrs at temperature of 28 - 30°C; the newly hatched larvae (before mouth opening) measured 2.72 ± 0.02 mm (zero-day-old). Two-day-old larvae (mean length is 2.74 ± 0.03 mm; the mouth gape is 0.19 ± 0.14 mm) were stocked randomly in two groups of three 20 l tanks at 500 larvae / tank or 25 larvae / liter and the larvae were fed on rotifers and egg - yolk particles respectively. Feeding began on the day of stocking. The larvae were fed rotifers for the first 12 days, followed by larger zooplankton mainly neonates of *Ceriodaphinia cornuta* (cladocerans) obtained from the culture maintained in the laboratory. The feeding density of rotifers ranged from 10 on day 2 - 15 /ml on day 12. Similarly the feeding density of cladocerans ranged from 5 on day 13–10 neonates per ml on day 16. The detailed feeding regime is given in Figure135.

For feeding of egg - yolk particles, hard boiled egg - yolk was first crushed and mixed with water and then sieved through a 150 µm mesh net. Those particles retained by an 80 µm mesh net were used for feeding. About 500 ml of algal water of *C. ellipsoidea* was added to all the tanks daily. The uneaten food and sediments were siphoned off and about 10 - 25% of water in each tank was replaced with well aerated filtered freshwater to maintain a low level of free ammonia (<0.02 µg/l). The water quality parameters especially temperature, dissolved oxygen and ammonia were monitored daily. The recorded range of values for various water quality parameters during the period of experiment are as follows: Temperature - 29 - 30°C; pH - 7.14 - 7.32; Dissolved oxygen - 5 - 8

mg/l; Nitrite -0.1 - 0.13 µg/l; Ammonia - 0.01 - 0.02 µg/l. The experiment was terminated on day 16, by which time all the larvae had consumed the larger zooplankton prey and the rotifers were completely avoided by the larvae and not consumed even though rotifers were present in the larval rearing tank. All the data with replicates are presented as means ± SD. The differences in growth and survival between the treatments were tested for statistical significance with student ('t') - test.

Feeding behavior and prey selectivity of the larvae: Four rotifers *Brachionus angularis*, *B. caudatus*, *B. plicatilis* and *B. calyciflorus* with different size range were tested as food for larvae to study the impact of prey size on larval growth. Mean lorica length of *B. angularis*, *B. caudatus*, *B. plicatilis* and *B. calyciflorus* were 107 ± 14 µm (range: 80 –120 µm), 157 ± 10µm (range: 138 – 175 µm), 198 ± 10 µm (range: 180 – 225 µm) and 291 ± 14 µm (range: 230 – 320 µm) respectively. Similarly, the width of those rotifers was 80 ± 5 µm (range: 50 - 88 µm), 103 ± 6 µm (range: 86 – 119 µm), 170 ± 4 µm (range: 156 – 175 µm) and 193 ± 16 µm (range: 160 – 220 µm) respectively. Experiments were carried out in glass beaker with 200 ml of filtered freshwater, with gentle agitation by bubbling. Each beaker contained one larvae of same age. Larvae of age 2 – 7 days were used for the experiment. The larvae were introduced into the experimental beaker with a known quantity of rotifer mixture and maintained (*B. angularis* + *B. caudatus* + *B. plicatilis* + *B. calyciflorus* at a rate of 5 + 5+ 5+ 5 = 20 /ml) for duration of 12 hrs. The preference of larvae and rate of consumption for each taxon were recorded after a specific interval. Five replicates were carried out for each experiment and the mean values were taken. Rotifer densities in the experimental beakers were examined at intervals of one to two hours, in order to obtain a significant, but not excessive difference during each period. The feeding behavior of early and advanced larvae was also observed. Selection between the different sizes of rotifer species was examined using the following index, derived from Ivlev (1955), cited by Yurochko (1976):

$$\text{Electivity} = \frac{r - p}{r + p}$$

Where, r = % of one organism in the total ingested; p = % of occurrence of the same organism in the medium. Thus the electivity ranges between +1 and -1, and is a measure of positive or negative selectivity of a specified prey organism. Furthermore, the mouth gape of the larvae at different age was measured and calculated the preferable prey size, assuming a mouth opening of 45° to be most frequent phenomenon of feeding larvae of the given species (Dabrowski and Bardega, 1984).

RESULTS

Pearl gourami larviculture experiment: Comparison of the performance of pearl gourami larvae fed on rotifer with those fed on egg-yolk is given in Table 54. The growth of the larvae in the rotifer group was faster than the egg - yolk group. The mean total lengths at the end of the day 12 and day 16 were 7.51 ± 0.49 mm and 9.46 ± 0.80 mm respectively in the rotifer group, were significantly larger than 4.84 ± 0.53 mm ($p<0.01$) and 5.64 ± 0.63 mm ($p<0.01$) respectively in the egg-yolk group. The mean survival rates of the larvae in the rotifer group were high in both stage 1 (upto day 12) and Stage 2 (on the day from 13 to day16), 98.93% and 98.54% respectively, significantly higher than 55.30% ($p<0.01$) and 45.77% ($p<0.01$) respectively in the egg-yolk group (Table 54). The overall mean survival rate (upto day 16) in the rotifer group (96.93 ± 1.54%) was more than twice that observed in the egg-yolk group (36.7 ± 5.17%).

Food selection and feeding habits of pearl gourami larvae: Feeding first began with the early larval stage at a length of about 2.74 ± 0.03 mm and with a mouth gape of about 0.19 ± 0.14 mm. First feeding larvae were 'strike feeders'. After making visual contact with a food particle, larvae oriented towards

it, bringing it into the visual field of both eyes. Next, the larvae slowly approached the particle to the possible nearest spot. At this point, the larvae either rejected it or swam away or 'struck' using one of the two behaviors. The first, which was more common in early larvae, was to curl the trunk into 'S' shape and lunge forward, at the same time opening the mouth. In the late or advanced larvae, swimming strength increased so as to dart forward by rapid swimming motions of the trunk and tail. The former behavior carried the larvae forward about half of the body length; the latter achieved a greater strike distance. When a strike was unsuccessful, successive strikes often followed, as long as the particle remained within the larva's visual field.

The mean values of Ivlev's electivity index for *B. angularis / B. caudatus / B. plicatilis / B. calyciflorus /* larvae are given in Table 55. In this experiment larva showed a clear age effect on their feeding preference of different size rotifers. The two-day-old larvae tended to choose rotifers between 80 - 120 µm (*B. angularis*) and the rotifers larger than 125 µm were rejected totally (E. index value for *B. angularis* was + 0.20). The three-day-old larvae tended to choose rotifers between 80 - 175 µm (*B. angularis* + *B. caudatus*; the electivity index for former was +1 and that of the later was +0.58 respectively) and the rotifers longer than 175 µm were rejected totally. Similarly the 4 and 5 day-old-larvae tended to choose rotifers between 138 µm and 230 µm (E. index value for *B. caudatus* was +1 and + 0.31; the E. index value for (*B. plicatilis*) was -1 and +0.84 on 4^{th} and 5^{th} day respectively) and rotifers longer than 250 µm were rejected completely. A complete rejection of *B. angularis* (E (A) -1) and reduced rate of ingestion of *B. caudatus* (E (B) -0.33) by the larvae were observed on the 6^{th} day. The seven-day-old larvae tended to choose rotifers between 180 µm and 320 µm (E. index value for *B. plicatilis* was +1 and the E. index value for *B. calyciflorus* was + 0.78) and the rotifers longer than 350 µm and shorter than 180 µm were totally rejected. From the 7^{th} day onwards the larvae were exclusively reared with *B. calyciflorus* (range: 230 µm to 320 µm) upto 12^{th} day. The 12-day-

old larvae tended to choose the food particle size longer than rotifers (>500 µm) such as neonates of *C. cornuta* (cladocerans).

DISCUSSION

The experiment in 20-liter tanks had demonstrated the usefulness of rotifers for larviculture of pearl gourami. The mean total length of the larvae in the rotifer group was significantly longer than in the egg-yolk group, indicating that feeding rotifers accelerated the growth of the fish larvae. The mean survival rate during the period also increased significantly, from 55.30% in the egg-yolk group, to 98.93% in the rotifer group (upto 12days). Although all the larvae in the egg-yolk group and the rotifer group were fed solely on neonates of *C. cornuta* (cladocerans) from the 13th day onwards, the survival and growth of the rotifer group continued to be significantly better than the egg-yolk group. These findings confirm that the use of rotifers for feeding gourami larvae from day 2 to 12 effectively enhanced their growth performance. Fish that were fed suboptimally would continue to suffer from poor performance later. On the day 16, the overall survival rate of larvae fed on rotifers in the tank was (96.93%) almost three times of that obtained in the tank using egg-yolk particles (36.70%). A high survival rate and growth of dwarf gourami, brown discus and three spotted gourami larvae fed on rotifers (*B. calyciflorus* and *B. plicatilis* respectively) had been reported by Lim and Wong (1997) from Singapore and Gopakumar (1998) from Kerala respectively better than the traditional rearing method. A high survival rate and growth of the pearl gourami larvae fed on rotifers was observed in the present study, which is in agreement with the findings of the above mentioned authors.

The observations on feeding morphology and behavior indicated that from the time of first feeding, larvae are selective 'strike' feeders, rather than pump

feeders like silver carp (Mathias and Li, 1982) and therefore, their feeding success depended upon vision and their ability to pursue and catch prey, as well as on the prey's size and ability to escape. Size-selective predation by planktivorous fish occurs within the morphological limits set by mouth size and gill raker spacing (Wankowsky, 1979), since the size of the prey eaten by the fish larvae is a function of the larval mouth width. According to the observation of Hunter (1980), in nature the mean diameter of the prey consumed by fish larvae was only 38% of their mouth width. In the present study, the mouth size of 2.74 ± 0.03 mm larvae was only 0.4 - 0.6 times longer (0.17 mm - 0.20 mm gape) than the size of the preferred zooplankton (range: 80 - 120 µm) and the rate of increase in mouth width as larvae grew from 2.74 mm to 7.51 mm coincided with the rate of increase in the average maximum size of rotifers taken as prey. As larvae grew from early larvae to advanced larvae, their prey-capture ability became much stronger and they shifted from smaller, slower prey to larger and faster organisms. Mathias and Li (1982) made a similar observation on the feeding behavior of walleye larvae in nature and in laboratory. Fukuhara (1983) observed that the first feeding larvae (early larvae) had relatively slow swimming speed and low capture success at onset of feeding (2-10%) of larval black spongy (*Acanthophagus schlegeli*). In the present study also the early larvae recorded low capture success 10 - 20% far less than that 70 - 80% achieved by the advanced larvae.

The experiment with a mixture of different sizes of rotifers showed a clear age effect on the larval feeding preference of different size rotifers. Early larvae, upto 3rd day after hatching preferred small rotifers such as *B. angularis* (size: 80 to 120 µm) and *B. caudatus* (size: 138 - 175 µm) and avoided feeding on rotifers larger than 175 µm, while in older larvae the feeding pattern was reversed. Similar observations were made by Helps (1982) who, found that gilthead seabream larvae showed a clear age effect on their feeding preference of different strains of *B. plicatilis* and the presence of small rotifers for the first few

days of feeding was associated with an improved growth rate. Lasker *et al.* (1970), Hunter (1980), Hunter and Kimbrell (1980), Beyer and Laurence (1981) and James and Rezeq (1989) had observed that in nature, fish larvae showed a tendency to feed on progressively larger prey as they grew. The present study confirmed that the larvae of pearl gourami as they grew had developed a preference to feed on rotifers of different size (particle size) corresponding to their age.

The use of rotifers is likely to have an important impact on the larviculture of pearl gourami and the ornamental larviculture industry as a whole. The application of the rotifers would enable intensive larviculture of freshwater ornamental fish species with small larvae, which would eventually lead to exponential increase in the yield of the fry, as demonstrated in this study. The availability of the small live food organisms would also facilitate breeding of new fish species with small larvae that could not be raised previously using the existing macro-zooplankton or extensive culture method. This would eventually enhance the number of fish species for breeding.

Furthermore, the same methodology can be adopted to evaluate the effect of age of various marine potential finfish species chiefly grouper (*Epinephelus tauvina*) and mullet (*Mugil cephalus*) larvae on their preference for haline rotifers of different sizes. Although *B. plicatilis* and *B. rotundiformis* 'S' type are the most suitable food organisms for marine fish larvae, their size restricts to their use for small mouthed fish larvae like grouper and mullet. The standard length of grouper (*E. tauvina*) and mullet (*M. cephalus*) larvae are 1.5 mm to 1.9 mm and 1.4 mm to 2.4 mm respectively (Lim, 1993; Lavens and Sorgeloose, 1996). Mouth gape at first feeding of *E. tauvina* was about 150 µm to 180 µm (Maneewong, 1986) and the same for *M. cephalus* was about 150 µm to 190 µm (Liao, 1975). Therefore, the larvae are expected to prefer the first prey that range from 80 to 100 µm, shifting within a few days to prey organisms that are >150 µm

(James and Rezeq, 1989). According to Tamaru *et al.* (1991), Marietta *et al.* (1997) and Ooziki *et al.* (1992), both grouper and mullet larvae fed on *B. rotundiformis* 'ss'[1] (size: 98 -171 µm) followed by *B. rotundiformis* 'S' type (size: 136 µm to 212 µm) were significantly longer and survived better than the larvae fed on *B. rotundiformis* 'S' type alone and the mean size of rotifers found in the gut increased as larvae grew. Therefore, early larvae preferred small *Brachionus* (a size <100 µm) especially during the first three days of feeding. In the present study, three morphologically and ecologically distinct haline rotifers (*B. plicatilis*, *B. murray* and *B. rotundiformis*) were represented in the plankton collections and these rotifers were isolated and successfully cultured in the laboratory over a period of year. The various experiments conducted in the laboratory revealed that these rotifers could be cultured in a wide range of salinity and temperature by using different types of microalgae from either brackishwater or marine environments. Therefore, these rotifers can be successfully used in larviculture of groupers and mullets in India.

Similarly, the size range of *B. angularis* is 80 - 120 µm (length) and 50 to 88 µm (width). This rotifer though freshwater in origin occurred in moderately saline waters of Veli -Aakulam estuary. In the laboratory also, *B. angularis* could be reared upto a salinity level of 10 ppt by gradual acclimatization. However, Miracle *et al.* (1987) has reported that *B. angularis* could tolerate a salinity range from 0.5 ppt to 24 ppt. Hence, gradual acclimatization of this species at different salinity levels could lead to a successful culture of this species at high salinity levels. Thus *B. angularis* can also be used as a suitable first live food for marine finfish larvae of small size especially grouper and mullet larvae since it is smaller than *B. rotundiformis* 'ss' type (the current small rotifer among the haline rotifers).

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[1] Three morphologically distinct haline rotifers are widely used in marine finfish larviculture. Based on the lorica size they are named as *B. plicatilis* ('L' type), *B. rotundiformis* ('S' type) and *B. rotundiformis* ('ss' type) by aquaculturists. Among these, *B. plicatilis* and *B. rotundiformis* 'ss' type are well corresponded to Muller's *plicatilis* and Tschugunoff's *rotundiformis*. However, the taxonomic status of *B. rotundiformis* 'S' type is not established till date eventhough this taxon is genetically related to *B. rotundiformis* 'ss' type.

Since the success of larval rearing depended on the efficient transition from endogenous to exogenous nutrition, i.e. meeting the corresponding metabolic demands of the larvae at different stages of their development, the knowledge of feeding requirements would allow better management of early larval rearing and also the introduction of new feeding methods.

Fig. 135: Feeding scheme for experimental larviculture of *Trichogaster leeri*

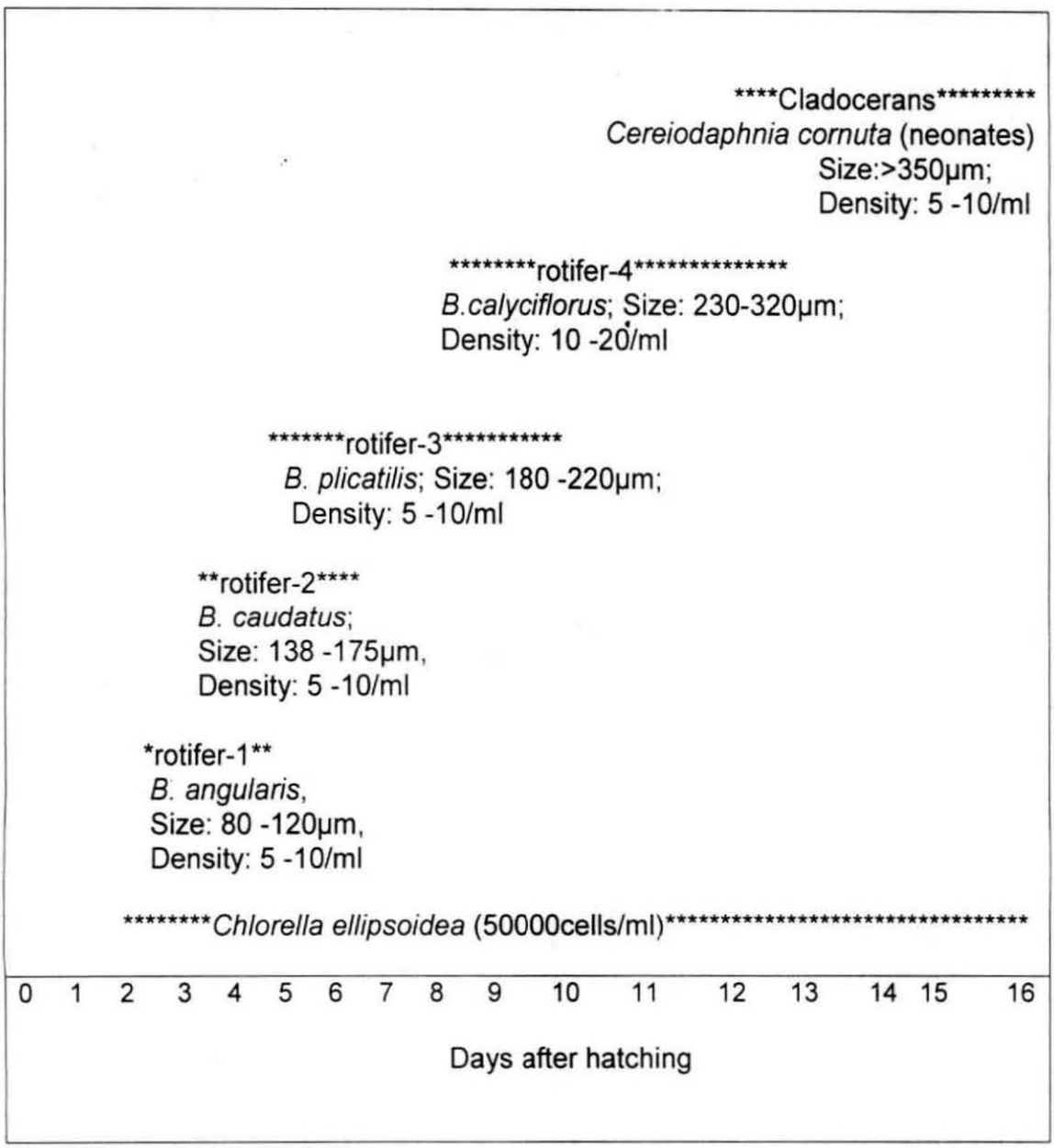

Table 49: Comparison of the performance of pearl gourami (*Trichogaster leeri*) larvae fed on rotifer with those fed on egg - yolk particles in 20 l aquarium tanks.

Feeding groups	Fed with rotifer	Fed with egg-yolk particles	Student ('t') test 't' value	p value
	Total length (mm)			
Day12 (rotifer group)	7.51 ± 0.49	4.84 ± 0.53	10.73	p<0.01
Day16 (Cladocerans)	9.46 ± 0.80	5.64 ± 0.63	9.58	p<0.01
	Survival (%)			
Stage-1 (Day 2 -12)	98.66 ± 0.77	55.30 ± 5.27	36.82	p<0.01
Stage-2 (Day 12-16)	97.33 ± 1.88	45.77 ± 4.57	40.59	p<0.01
Overall survival (Day 2-16)	96.00 ± 0.35	36.70 ± 5.17	36.01	p<0.01

Table 50: Selection of rotifers by larvae as a percentage of rotifers in the water (Electivity index value for rotifers of different size)

Age of larvae Days	Food density (rots/ml) (A-5+B-5+C-+D-5)[1]	Co - Ct [2]	E (A) [3]	E (B) [4]	E (C) [5]	E (D) [6]	Mouth gape of larvae (mm)
2	20	20-18 (3+5+5+5)	+0.20	-1.00	-1.00	-1.00	0.172-0.20
3	20	20-12 (0+2+5+5)	+1.00	+0.58	-1.00	-1.00	0.205-0.24
4	20	20-12 (2+0+5+5)	+0.57	+1.00	-1.00	-1.00	0.241-0.25
5	20	20-11 (5+1+4+1)	-1.00	+0.31	+0.84	-0.56	0.290-0.31
6	20	20-10 (5+2+0+3)	-1.00	-0.33	+1.00	+0.78	0.310-0.40
7	20	20-10 (5+5+0+0)	-1.00	-1.00	+1.00	+1.00	0.325-0.42

1: A: *Brachionus angularis* (80 –120 µm); B: *B. caudatus* (138 –175 µm); C: *B. plicatilis* (180 – 220 µm); D: *B. calyciflorus* (230 – 320 µm)
2: Co: Initial rotifer density; Ct: Final rotifer density in the larval rearing tank
3: Electivity index value for *B. angularis*
4: Electivity index value for *B. caudatus*
5: Electivity index value for *B. plicatilis*
6: Electivity index value for *B. calyciflorus*

CHAPTER 6

THE EFFECT OF FEEDING OF ROTIFER (*BRACHIONUS ROTUNDIFORMIS*) UPON SURVIVAL AND GROWTH OF LARVAL MARINE SHRIMP, *PENAEUS MONODON*

INTRODUCTION

Over the past two decades shrimp mariculture has increased world wide. Uncertain supply and the exorbitant cost of wild post larval seedstock has encouraged the growth of hatchery technology for the culture of penaeid shrimp larvae. The development of shrimp larvae is characterized by a number of stages, each requiring different feeding regimes according to behavior, morphology and nutritional requirements. A nutritionally balanced introductory feed is the key to successful larviculture. Hence, feeding of larvae still continues to be an active field of research of critical significance in all aquacutlurally advanced nations.

Feeding is one of the most important factors affecting larval development of penaeids. Generally, the diets used during penaeid culture are based on a mixture of algae, primarily diatoms, during the early stages. The need for an animal protein as a component of the larval diet was first recognized by Hudinaga (1942). The food most commonly chosen to fulfill this need has been the brine shrimp, *Artemia* (Sorgeloos, 1980). The rotifer especially *Brachionus plicatilis* has also been recognized as a potential food organism in addition to or as a replacement for *Artemia* (Hirata *et al.*, 1975, 1985; Hudinaga and Kittaka, 1967; Cook and Murphy, 1969; Shigueno, 1975; Sorgeloos and Person, 1975; Kittaka, 1976; Rodriguez, 1976; Solangi and Ogle, 1977; Lumare *et al.*, 1978; Emmerson, 1980, 1984; Mock *et al.*, 1980; Yúfera *et al.*, 1984; Léger *et al.*, 1985, 1989; Samocha *et al.*, 1989; Millamena *et al.*, 1990; Yúfera and Lubian, 1990; Liao *et al.*, 1993). In production systems, animal food is an important factor in over all production cost. Offering the correct food at optimal densities for each larval stage is necessary for efficient and economic hatchery operation. However, there is practically no information concerning the suitability of rotifer as a food source for penaeid larvae from India. To fill up this gap, the present study was

undertaken to evaluate the suitability of rotifers as a supplementary food resource for the zoea (= protozoea) substages of *Penaeus monodon*, a species of highest commercial importance in India and abroad.

MATERIAL AND METHODS

Diatom culture: The inocula of the mixed diatoms dominated by *Chaetoceros* spp. was obtained from State Fisheries Hatchery, Thirumulavaram, Kollam and this stock was inoculated into a 100 - 150 liter Perspex tank filled with filtered fresh sea-water at a salinity of 34 ppt to 35 ppt. Before the inoculation the filtered seawater was enriched with Sodium nitrite (12 mg/l), Potassium orthophosphate (6 mg /l), EDTA (6 mg/l) and Sodium meta silicate (1 mg/l). The culture was exposed to sunlight and agitated by mild continuous aeration. When the culture had reached a cell concentration of 3 - 4 lakh cells/ml, the diatom culture was harvested and fed to larvae.

Rotifer culture: *Brachionus murray* was cultured solely in marine *Chlorella salina* at around 2 - 4 million cells/ml. Their mass culture was performed using a batch culture system in the outdoor culture tanks (100 - 150l capacity) at room temperature (28 - 32°C) and at the salinity of 20 ppt to 25 ppt. The culture tanks were provided with continuous aeration. Stocking density was 25 - 40/ml and the total harvest was conducted after 5 days when the population has attained a density of 75 –100/ml. The size of the rotifer ranged from 136 µm - 212 µm.

***Artemia* production (nauplii)**: *Artemia* cysts (San Francisco Bay strain) were incubated in natural sea water for 24 hours at 3 g to 5 g cysts per liter. Water temperature was kept at 30°C with a continuous illumination of 1000 lux.

Aeration was supplied to keep the cysts in suspension throughout the 24 hr incubation period. Nauplii (unfed) were separated from the cysts and harvested by siphoning. The body length and width of the newly hatched nauplii were 335 - 520 µm and 110 - 220 µm respectively.

Rearing techniques: Nauplii of *P. monodon* were obtained from the Kerala State Fisheries Hatchery, Thirumulavaram (Kollam). Two groups of nauplii at a rate of 20 nauplii per liter from the stock were placed in the plastic troughs of 50 l capacity filled with filtered fresh sea water at room temperature (29 - 31°C) and salinity of 32 ppt to 35 ppt agitated by bubbling and subjected to continuous illumination. Two sets of feeding protocols were adopted. In the first set the larvae were fed solely with mixed diatom (20,000 - 25,000 cells/ml) upto mysis III stage and later on *Artemia* nauplii were fed to the larvae whereas in the second set of experiment the larvae, zoea I were fed with rotifer in the place of algae at a rate of 25 - 30 rotifers per ml upto mysis III stage. Freshly hatched *Artemia* nauplii were supplied when the shrimp larvae moulted into post larvae1. From the 3rd day onwards daily 1/4th water from the larval rearing tank was removed and replaced with fresh filtered sea water. The debris and uneaten food were daily removed by siphoning. The water quality and other conditions conducive for larval tanks were monitored and values of the parameters were as follows:

Salinity	32 ppt to 35 ppt
Temperature	29 - 32°C
PH	8 - 8.5
Dissolved oxygen	5 - 7 mg/l
Total ammonia	0.05 - 0.1 µg/l
Nitrite	0.05 - 0.1 µg/l

Triplicates were maintained for each experiment. Survival and growth of larvae fed on diet with rotifer addition and those on the diet without rotifer

addition were recorded daily. The data were subjected to't' test (Student test). The duration of experiment was 10 days.

RESULTS

The range of body length and the corresponding period of time taken for development of each stage are given in Table 56. The duration of naupliar stage was about two days and its size ranged from 0.31 mm at N - I to 0.53 mm of N - VI. The nauplii metamorphosed into post larvae -1 between 9^{th} and 10^{th} day of the experiment. The size of the post larvae -1 ranged from 4.25 mm to 4.70 mm. Comparison of the growth performance and survival of each larval stage fed on the diet with rotifer and those fed on the diet without rotifer are summarized in Tables 57 and 58 respectively. The results revealed that the naupliar, zoea Z-I to Z-II and mysis M-I to M-II substages did not show any significant difference in growth between the larvae receiving rotifer and those without rotifer, as the mean body length of the larvae fed with rotifer was slightly more as evident from Table 57. At the stage of zoea - III, the mean total length of rotifer fed larvae was 2.29 mm, significantly higher than those without rotifer diet ($p<0.01$). Similarly, the mysis-III stage and post larvae - 1 stage, the mean total length of the rotifer fed larvae were 4.29 mm and 4.61 mm respectively, significantly higher than the 4.20 mm and 4.53 mm obtained for the larvae fed on diet without rotifer ($p<0.05$).

The mean survival rate of the naupliar and zoea-I stages of larvae in the rotifer fed group and that without rotifer as food did not show any significant variation (Table 58) whereas, the survival rate of the mysis stage (M -I to M -III) in the rotifer group was significantly higher than in the diet without rotifer ($p<0.05$). Similarly, the over all survival rate (upto Day 9) in the rotifer group (94.67%) was significantly ($p<0.01$) higher than in the diet without rotifer (upto Day 10) group (86.66%).

DISCUSSION

Numerous studies have focused on the optimal stage for the introduction of animal food into larval culture systems. The timing of the introduction of animal feed is important for a number of reasons. Prey organisms consume algae and dissolved oxygen in the culture vessels, thereby directly competing with larval shrimp for important resources which are at times in limited supply. Furthermore, they excrete poisonous metabolites, causing water quality problems. Prey organisms which grow quickly become invulnerable to predation. Thus, *Artemia* nauplii which are not consumed grow to adulthood greatly complicating the management of the hatchery tanks. The timing of the onset of raptorial feeding varies among penaeid larval predator species. Besides, the ability of penaeid larvae at given substages to consume zooplankton also depends on the type and size of the prey organisms.

Feeding the penaeid species only with *Artemia* nauplii from the late mysis stage onwards has been in practice for long. However, decrease in survival has been noted as penaeid larvae metamorphosed to the mysis substages and as they change over from an algal diet to a diet including *Artemia* nauplii (Mock *et al.*, 1980). Hence, it was suggested that a food organism intermediate in size between algae (5 µm to 50 µm) and freshly hatched *Artemia* nauplii (450 µm to 500 µm) could increase survival and growth rates (Mock *et al.*, 1980). Attempts have been made by various workers to determine a suitable food for zoea larvae. Many species of diatoms have been used for this purpose. Single or mixed culture of diatom species have been used as common practice for the rearing of zoea stages (Cook and Murphy, 1969; Okauchi *et al.*, 1997). Because of the uncertainty of having good diatom culture available when needed, methods were developed by which concentrated diatom cells could be preserved (Hirata *et al.*, 1975; Leger *et al.*, 1985, 1989). Rotifers have also been used as good food for

prawn larvae due to its intermediate size (99 µm to 281µm) between the algal diet and *Artemia* nauplii (Hudinaga and Kittaka, 1967; Liao, *et al.*, 1993). Rotifers are consumed from zoea - II substage of *Penaeus japonicus* (Hirata *et al.*, 1985), *P. kerathurus* (Yúfera *et al.*, 1984) and *P. semisulcatus* (Watanabe, 1980; Samocha *et al.*, 1989). Similarly, *P. indicus* has been shown to consume rotifers as early as zoea-I (Emmerson, 1984). Rotifers have been used as supplementary feed for fresh water prawn, *Macrobrachium rosenbergii* (Lovett and Felder, 1988). All above reports revealed the suitability of rotifers as a good food source for prawn larvae. The present study also showed that the survival rate of post larvae were higher in the diet with rotifer than the diet without rotifer. Thus the present result indicates that rotifers could be used as supplementary food source for zoea substages of *P. monodon*. Hence, feeding the zoea substages of the penaeid larvae with rotifer as supplementary food source have contributed to the good larval survival (>90%) than the routine method. However, rotifers as a supplementary food source of zoeal stages needs further studies especially on the economic feasibility of this feeding regime in the larval production.

Table 51: The range of body length and the corresponding period of time taken for development of each stage *Penaeus monodon*

Feeding groups	Diet with rotifer	Diet without rotifer	Age (Days)
	Total length (mm)		
Nauplii (1-6)	0.31 - 0.53	0.31 - 0.52	2
Zoea -1 (Z-1)	1.05 - 1.09	1.04 - 1.08	3
Zoea -2 (Z-II)	1.65 - 1.68	1.63 - 1.66	4
Zoea -3 (Z-III)	2.14 - 2.38	2.13 - 2.29	5
Mysis -1 (M-I)	3.65 - 3.95	3.63 - 3.94	6
Mysis -2 (M-II)	3.90 - 4.37	3.79 - 4.37	7
Mysis -3 (M-III)	4.15 - 4.40	4.00 - 4.33	8
Post larva (PL-1)	4.45 - 4.70	4.25 - 4.58	9

Table 52: Comparison of the growth performance of *Penaeus monodon* larvae fed on diet with rotifer and those fed on diet without rotifer

Feeding groups	Diet with rotifer	Diet without rotifer	Student ('t') test 't' value	p value
	Total length (mm)			
Nauplii1-6 (N I-VI)	0.48 ± 0.02	0.48 ± 0.02	0.826	0.43
Zoea-1 (Z-I)	1.07 ± 0.01	1.06 ± 0.01	1.677	0.12
Zoea-2 (Z-II)	1.67 ± 0.01	1.65 ± 0.01	6.530	0.00**
Zoea-3 (Z-III)	2.29 ± 0.07	2.25 ± 0.05	2.714	0.20
Mysis-1 (M-I)	3.82 ± 0.16	3.78 ± 0.09	1.254	0.24
Mysis-2 (M-II)	4.15 ± 0.05	4.11 ± 0.19	0.745	0.47
Mysis-3 (M-III)	4.29 ± 0.09	4.20 ± 0.07	2.549	0.03
Post larva (PL-1)	4.61 ± 0.08	4.53 ± 0.12	2.558	0.03

*p<0.05; ** p<0.01

Table 53: Comparison of the survival of *Penaeus monodon* larvae fed on diet with rotifer and those fed on the diet without rotifer

Feeding groups	Feeding schedule with rotifer	Feeding schedule without rotifer	Student ('t') test	
			't' value	p value
	Survival (%)			
Nauplii(N1-6)	100 ± 0.00	100 ± 0.00	0.00	1.00
Zoea(Z1-3)	100 ± 0.00	98.26 ± 2.36	2.45	0.37
Mysis (M1-3)	98.5 ± 2.54	95.37 ± 2.42	4.40	0.02*
Post larva (PL-1)	97.3 ± 2.31	92.50 ± 2.77	3.19	0.11
Overall survival	94.67 ± 2.31	86.66 ± 2.31	4.82	0.01**

* $p<0.05$; ** $p<0.01$

SUMMARY

01. The history of the systematics of the phylum Rotifera is traced through the literature from Linnaeus (1758) to the present day. A comprehensive account of Indian rotifers is also provided.

02. Forty-four species of rotifers belonging to 16 genera and 12 families are recorded. Description of 22 species including four subspecies and 40 forms belonging to the family Brachionidae found along the southern coast of Kerala are furnished. Illustrations of the different characters of taxonomic value are also presented. Among these, *Brachionus dichotomus reductus*, *B. kostei* and *B. urceolaris nisoni* are new records for India and *B. quadridentatus mirabilis* and *B. calyciflorus borgerti* are new records for Kerala. In this investigation it was revealed that *B. plicatilis* is not a single species in the brackish waters of Kerala but a complex of at least three morphologically recognized taxa, B. *plicatilis* (so-called 'L' type), *B. murray* (*B. rotundiformis* 'SM') and B. *rotundiformis* (*B. rotundiformis* 'ss' by aquaculturists). *B. havanaensis trahea* is recovered and redescribed and its earlier name was *B. forficula keralaiensis* from Irinjalakuda (Kerala) as a variety of *B. forficula*.

03. Species composition, population density and distribution of rotifers in relation to physico – chemical parameters and algal blooms were investigated at two stations in Poonthura and at three stations in Veli – Aakulam estuaries from February 2000 – January 2001.

04. The rotifer component in Poonthura estuary was represented by 12 families, of which families Brachionidae, Lecanidae and Filiniidae were represented by seventeen, six and three species, respectively. Family Lepadellidae was represented by two species whereas the families of Asplanchnidae, Testudinellidae, Synchaetidae, Epiphanidae, Mytilinidae, Trichotridae, Euchlanidae and Hexarthridae had only one species each.

The dominant species in this estuary was *B. angularis*, *B. plicatilis*, *Keratella cochlearis* and *B. calyciflorus*. The highest number of species and population density were noted during the pre-monsoon and post-monsoon periods. *Brachionus kostei* was noted only in the month of February whereas *Platyias quadricornis* and *P. leloupi* were recorded only in August.

05. In Poonthura estuary, the impact of different environmental parameters on the dominant species *B. angularis*, *B. plicatilis*, *B. calyciflorus* and *K. cochlearis* has been described with the help of correlation analysis and the results showed that pH, dissolved oxygen, total alkalinity and nutrients were significantly correlated with abundance of these dominant species in the study.

06. Monthly and seasonal variations in the diversity indices of the rotifers of Poonthura estuary were analyzed and the results of the analyses showed that diversity, species richness and evenness indices of rotifers were high during the pre-monsoon period while the dominant index alone was high during the post-monsoon period.

07. The rotifers of the Veli - Aakulam estuary were represented by 31 species belonging to 16 genera and 12 families. The dominant genera in this estuary were *Brachionus*, followed by *Filinia* and *Lepadella*. Among the brachionids, *B. angularis*, *B. plicatilis*, *B. calyciflorus* were the most abundant and most of the other species were noted during pre-monsoon and monsoon periods. The haline rotifer *B. murray* was recorded during the monsoon and post-monsoon periods particularly in the month of June, September and January. However, *B. rotundiformis* was recorded only in the month of September.

08. Correlation analysis between the dominant species and various hydrographical parameters had shown that nitrate had exerted significantly important influence on *B. angularis* and *B. calyciflorus* at Station III (Aakulam) alone whereas both nitrate and salinity had the same effect on *B. plicatilis*. On the other hand, dissolved oxygen and silicate were found to be significantly related with *B. murray*.

09. In Veli - Aakulam estuary, the rotifers were associated with phytoplankton blooms such as *Microcystis aeruginosa* in May, *Chaetoceros* spp. (diatom) in September, *Cyclotella* sp. (diatom) in January and a mixed phytoplankton bloom in July. In this estuary, blue-green algal blooms dominated by *Microcystis aeruginosa* had exerted a negative influence on rotifer community in general. However, diatom blooms dominated by *Chaetoceros* spp. and *Cyclotella* sp. showed a positive influence on the rotifer density. Among the rotifers, *B. murray* showed its maximum population density when the bloom of *Chaetoceros* spp. was recorded, followed by *Cyclotella* sp. whereas other brachionids showed a reverse trend. The present finding also corroborates with the results of the reproductive potential of this species as given in the chapter 3.

10. Six rotifer species namely *B. angularis*, *B. caudatus*, *B. calyciflorus*, *B. plicatilis*, *B. murray* and *B. rotundiformis* were isolated and studies were conducted on the impact of salinity, temperature, feed concentrations and feed type on different biological aspects such as reproductive potential and life table parameters of these rotifers.

11. The impact of feed type, feed concentration, salinity and temperature on reproductive rate of rotifers was examined. The results of this study showed that all these parameters had a significant influence on reproductive potential of different rotifer species. These parameters acted

independently as well as interacted with each other in varying magnitudes. The most crucial factors influencing the reproductive rate of rotifers were salinity and food. *B. angularis*, *B. caudatus* and *B. calyciflorus* yielded their highest reproduction at the low salinity of 0. 5ppt and the 'r' values declined as the salinity increased from this level since these are though fresh / brackish water rotifers they can still tolerate salt concentration to a certain extent (upto 10 ppt). *B. plicatilis*, *B. murray* and *B. rotundiformis* recorded their highest 'r' value at salinities of 5 ppt, 10 ppt and 15 ppt respectively. Similarly, all the rotifers yielded their highest 'r' values at temperature of 28 - 30°C (room temperature). However, *B. rotundiformis* did not show any significant difference between the thermostat temperature of 35 - 37°C and the room temperature chosen for the present study. Among the different algal feeds, *Chlorella ellipsoidea* was found suitable for *B. angularis*, *B. caudatus* and *B. calyciflorus*. Similarly, the suitable feed for *B. plicatilis*, *B. murray* and *B. rotundiformis* were *C. salina* and *C. infusorium*, *C. calcitrans* and *I. galbana* respectively. It was also observed that the concentration of different feed types had a significant influence on reproductive potential, which is dependent on the type of the feed and ingestion capacity of the rotifers. Hence the concentration of feed required for the optimum 'r' value for a particular rotifer varies with the particle size. Among the freshwater algal species *S. protuberans* is larger than *C. ellipsoidea, C. infusorium* and A. *convolutes* and hence its concentration requirements is proportionately lower than that of above mentioned algal feeds for *B. angularis, B. caudatus* and *B. calyciflorus*. Similarly, the marine alga *Tetraselmis gracilis* is larger than that of *C. salina*, *I. galbana* and *C. calcitrans*, and hence its concentration requirement is comparatively less than that of other marine algal feeds.

12. The influence of temperature and salinity on their life history characteristics was investigated. The results of the this study showed that

the life table parameters were vitally affected by salinity as well as temperature and this in turn influenced their survival, reproduction and growth. *B. angularis*, *B. caudatus* and *B. calyciflorus* had attained their maximum size, longest reproductive period, highest fecundity, longest lifespan and shortest juvenile period and egg hatching time at the salinity of 0.5 ppt. On the other hand, *B. plicatilis*, *B. murray* and *B. rotundiformis* attained their maximum size, longest lifespan, highest fecundity and shortest juvenile period and egg hatching time at the salinities of 5 ppt, 10 ppt and 15 ppt respectively. As regards statistical analysis (two-way ANOVA) salinity, temperature and salinity x temperature interaction had significant influence on various life table parameters particularly on lifespan, fecundity, reproductive period and egg hatching time.

13. The suitability of rotifers of different sizes as feed was evaluated on the basis of the survival and growth of the pearl gourami (*Trichogaster leeri*) larvae used as a test animal. The results of this study showed a clear larval age effect on their feeding preference of different prey sizes. Early larvae at the first feeding stage tend to prefer small rotifers, therefore avoided feeding on large rotifers, while in older larvae the feeding pattern was reversed. The mouth size of the larvae was significantly correlated with the size of the prey. In the present study, the mouth gape of the larvae was generally 0.4 - 0.6 times longer than the preferred prey size. A high percentage of survival and growth of the larvae fed on rotifers was noted when compared to those of the larvae fed on egg yolk particles.

14. The survival and growth of the prawn larvae of the commercially important tiger shrimp, *Penaeus monodon* fed on rotifers (*B. murray*) was evaluated in the present study. The use of rotifer as a supplementary food source substantially enhanced the larval survival; however, the growth rate of the larvae did not show any appreciable increase.

15. The present study provides the information on the systematics, ecology and general biological aspects of six brachionid species. It also throws light on the suitability of rotifers as an ideal first feed for finfish and shellfish larvae. The suitability of rotifers other than *B. plicatilis* and *B. rotundiformis* as a live feed for finfish larvae is likely to have an important impact on the larviculture industry as whole. The application of rotifers as first feed would enable intensive larviculture of both fresh water and marine finfish species with small larvae and that would eventually lead to increase in the yield of the fry.

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